GENERAL SCIENCE

CALDWELL AND EIKENBERRY

MAN'S CONQUEST OVER NATURE

ELEMENTS OF GENERAL SCIENCE

BY

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PREFACE

Science instruction in the first year of the high school has presented one of the most serious problems in secondary-school work. The results of modern science are extensively used in almost all kinds of human experience, and the scientist's way of working is recognized as the most reliable method. It is also generally recognized that education by use of science should lead to better understanding and better use of the types of scientific knowledge which relate to common experience. It is therefore the object of this course to develop a usable fund of knowledge about common things and helpful and trustworthy habits of considering common experiences in the field of science. It is expected that pupils' interests and abilities will be discovered and utilized in such ways that more effective and more profitable work may be done in the vocations or in later studies.

The course presented in this book is the result of ten years of experiment in secondary schools. Teachers of subjects other than science, and administrative officers who are studying the efficiency of the whole high-school curriculum, have been constant observers and critics of the experiment. Teachers who have used the course have made many contributions to it. Its present form and content are the outcome of the coöperative efforts of many science teachers who believe that the methods of experimental science must be used in organizing and testing science courses.

Our point of view is expressed by Professor Charles H. Judd in his introduction to the first edition, as follows:

There is a science of science teaching. This new science is young. It is not recognized as yet by many who profess themselves to be hospitable to every form of research. But the new science can afford to be patient. The greatest conquests of which the older sciences are so proud are all matters of a century, at most, and many of these conquests fall within the memory of our own generation. There are men now working in biology who remember well the beginnings of the modern period in that science. So it will be with the science of teaching. Once we realize the value of experimentation, once we take seriously the problem of adapting intellectual material to real needs, we may look for a rapid and satisfactory growth in this our new science.

The unity of this introductory course in science is secured by use of the logical interrelations between the topics which compose the course. No attempt is made to maintain the unity of any one of the different sciences. Experience shows that after use of this course pupils do not feel that they "have had" any of the differentiated sciences, as physiography, physics, chemistry, or biology. They are, however, much interested in the later study of the differentiated sciences. The topics of the course are readily grouped under six major divisions. Within these major divisions the topics are arranged so that there is coherence and progression in the work. The authors have selected the materials and have organized the course upon the ground of pedagogical value, as shown by classroom experiment.

The new edition has been almost entirely rewritten. The organization and method of the first edition are satisfactory in practice and are retained. Because of added scientific discoveries and educational experimentation it has been found desirable to add new material throughout. A few minor topics have been omitted. To the third major division, Work and Energy, chapters have been added upon the important topic Electricity. Following the discussion of the source of the energy used on the earth and preceding the division The

Earth's Crust there is an added topic, The Earth in Relation to other Astronomical Bodies. Considerable new material on nutrition and proper care of the human body is added. Particular attention has been given to relations which the studies bear to household problems as well as to those of the community and of the industries. At the beginning of each chapter a list of Questions for Discussion is given. It is expected that when beginning the work of each chapter the pupils and teacher will read and discuss the questions briefly. These questions recall pupils' previous experiences and set up new problems whose brief consideration gives significant purpose to the text and experimental work which follows. After the chapter has been studied, the questions provide the best means of review. About fifty additional illustrations are included.

Throughout the course there should be experimental work in the form of demonstrations, individual or group laboratory exercises, and home or school projects. A laboratory manual has been prepared to serve as a guide in the performance of experiments and demonstrations. The apparatus for use in experiments should be the most simple available, and that from the community or home may often be more educative than complex and costly apparatus.

The authors wish to express their appreciation for most helpful advice, suggestions, and criticisms given by Director Charles H. Judd, Principal F. W. Johnson, and Mr. Charles J. Pieper of The University of Chicago School of Education. In the revision Professor Allan W. Abbott of Teachers College, Columbia University, has read the entire manuscript to correct and improve it in English form and style; Director Alice F. Blood and Professor Ula M. Dow of the School of Household Economics of Simmons College have added much to the household applications of the course; Professors E. B. Frost of the Yerkes Observatory and

F. R. Moulton of The University of Chicago have contributed greatly to the chapters on astronomy; and Mr. Earl R. Glenn of The Lincoln School of Teachers College has given invaluable assistance in connection with the chapters on electricity, as well as in other parts of the revision. While recognizing the valuable assistance given by those to whom acknowledgment is made, the authors also assume full responsibility for the materials included in the book.

OTIS W. CALDWELL
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GENERAL SCIENCE

PART I. THE AIR

CHAPTER I

INTERESTING THINGS ABOUT THE AIR

1. Introduction. What men can do and where and how they can live often depend upon the atmosphere which surrounds us. Because of our constant dependence upon the air, there are many common questions which it is interesting to consider. We can answer most of these questions from our own previous experience, from experiments and observations we may make, or from written statements of the experience of others. The following are some of these questions, and as these are considered, and as experiments are performed and the text is read, each pupil will doubtless think of other questions about which he would like to know.

The questions which appear at the beginning of each chapter of this book are not intended to be answered fully when work on the chapter is begun. They are provided in order to add meaning to text discussions and to experiments and demonstrations. When work on each chapter is begun, the questions should be read and discussed briefly. At the close of each chapter the class should return to the questions and problems and make sure that all can be satisfactorily answered. The questions given show clearly the kind of significant problems which should be constantly in mind.

2. Questions for Discussion. **1.** Why does smoke go up a chimney? **2.** What are the reasons for placing furnaces in basements rather than in upper rooms of buildings? **3.** What is the purpose of a chimney on a house? **4.** How should the dampers in a stove or furnace be arranged when a fire is being started? **5.** Why does a check draft in a range or furnace cause the fire to burn more slowly? **6.** After a fire is started in a cookstove, what changes in the dampers should be made if the oven is to be heated? **7.** Why is the hot water in a heater drawn off from the top of the heater instead of from the bottom, near the fire? **8.** Why does a cake of ice in a refrigerator thaw more rapidly at the top than at the bottom? **9.** Why does a paper balloon with a lighted candle at the base tend to rise? **10.** Why is a room cooled more quickly if a window is opened at the top than at the bottom? Would the change of air be more rapid if the window were opened at both top and bottom? **11.** If a room is heated from a hot-air register in the floor at one side of the room, why does the opposite side of the room feel warm before the center? **12.** If we press an inflated rubber ball and then release it, it will resume its original shape. Why? **13.** When an empty bottle is suddenly submerged in water, air bubbles rise. Explain this fact. **14.** Why does a gas ball not bounce well after it has been punctured? **15.** If air is a gas, why does it hold up the weight of an automobile? **16.** Account for the report that follows the firing of a giant firecracker. **17.** What makes the air gun pop? **18.** How do air brakes work? **19.** Why is it easier to cook food in a closed vessel than in an open one? **20.** Can you heat water to a temperature of 125° C. (or 257° F.)? If so, how? **21.** How can the mercurial barometer be used in approximating the heights of mountains? **22.** Why do some people have a pain in the head over the eyes and ears or nosebleed when going up a high mountain? **23.** A pupil in school is said to require about 2000 cubic feet of air space per hour. Measure the schoolroom and determine the total volume of air in the room. **24.** How may the proper amount of fresh air be secured in your schoolroom?

3. Air as material. Most of the time we are quite unconscious of the air and, in fact, usually ignore its existence. For example, if there is a glass tumbler on the table before us, and this does not contain either a liquid or a solid, we say that it is empty. It is not empty, for it is filled with air; but since air is not visible we ordinarily do not recognize its presence (figs. 1 and 2). Similarly, we often say,

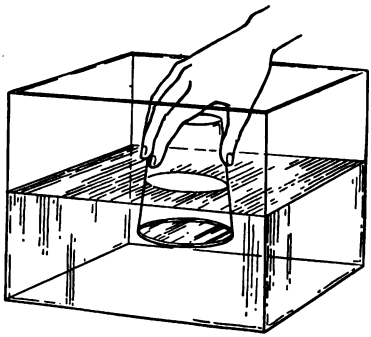

FIG. 1. Air occupying space

An experiment with an inverted glass showing that the air within the glass prevents the water from filling the glass

when we look out over the houses, tree tops, and open fields, that "there is nothing there," but if we go out of doors on a windy day, we may be very forcibly reminded that there *is* something there.

If we examine a bicycle tire or a football empty of everything but air, we may find proof that air does really fill things, for everyone knows that when you attempt to flatten out an inflated football or tire, it resists and shows evidence of being filled. All of these common

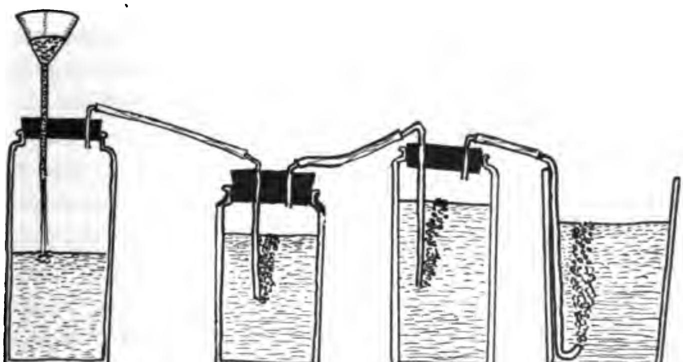

FIG. 2. An experiment by an eleven-year-old boy

This illustration is reproduced from a boy's drawing of apparatus which he prepared to prove that air occupies space. The following directions for the experiment were written by the boy, and neither the drawing nor directions have been changed in any way: "Materials, some glass and rubber tubing, three two-holed rubber stoppers, three bottles, and a tumbler, and also a funnel. Set the apparatus up as shown in cut, and be sure that all the connections are air tight. Pour water or any other fluid down the funnel. State what occurs. Why do the bubbles appear? Additional problem. When the last glass tube is covered up what occurs? Explain"

experiences, and many others, teach us that air is a very real substance, even though it is invisible, and that it occupies space as do other substances. This space-occupying property of air is useful to man in many ways.

4. Some uses of compressed air. As the drinking glass was forced down into the water, as shown in figure 1, the air was slightly compressed. This is shown by the fact that the water rose slightly in the glass. In automobile garages the compressed air is usually stored in strong tanks and when needed is placed in the tires through connecting tubes. The pumps used to inflate footballs and tires on bicycles or automobiles are devised to compress air rapidly and to force it into the tires.

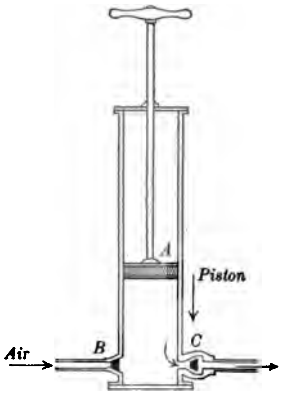

FIG. 3. Diagram of an air pump

When the piston *A* is forced downward the valve *B* is closed and *C* is opened

The inexpensive pump shown in figure 3 can be used to compress air if the amount of compression needed is not large. If the valves of the pump are reversed, the pump exhausts air instead of pumping it into the tire. Most commercial air pumps are similar in principle to the one shown in the figure. Air pumps are common in garages, on railway cars, and on street and interurban cars. In transportation cars compressed air is used in applying brakes, and everyone is familiar with the shrill noise made by the suddenly released air which has just been used in stopping the cars. Compressed air is also often used in blowing whistles and sirens; in operating compressed-air engines, heavy hammers used in construction work, and drills used in blasting rock and coal; and for driving the dentist's drill. It is used in operating automatic devices for regulating temperatures in homes, schools, and public buildings.

5. Measuring air pressure in tires. In order to secure the proper air pressure in an automobile tire and at the same time to avoid danger of bursting it, there is need for a means of measuring the pressure and also need for knowledge of the amount of pressure which will make the tire give the best service. Pressure gauges (fig. 4) as measuring devices are in common use. Various types of these gauges are manufactured for a variety of different purposes.

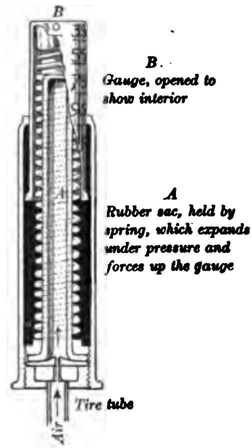

FIG. 4. Air-pressure gauge

By attaching this gauge to the air tube of an automobile or bicycle tire the amount of air pressure may be measured

Since the best service is secured by using them at the proper air pressure, it is now customary to take the tire manufacturers' recommendations on this point, and these may be secured from the salesman. The weight of the machine and load to be carried are considered in estimating the pressure, as is shown in the following table, which gives the pressures recommended for some of the commonly used kinds of tires:

DIAMETER OF TIRE	PRESSURE PER SQUARE INCH	REAR LOAD PER TIRE AVERAGE CONDITIONS
3 in.	45 lb.	375 lb.
4 in.	60 lb.	750 lb.
5 in.	70 lb.	1225 lb.
6 in.	75 lb.	1710 lb.

6. Working under water. In laying the foundations of bridge piers and other structures which must rest below water level (fig. 5), it is common for the laborers to work in a large steel chamber which has no floor and which rests upon the bottom of the lake or river. This is called a caisson.

The water is kept out of the caisson by the use of air pumps which force air into it with sufficient pressure to overcome the pressure of the water. The entrance and exit of workmen without allowing the escape of the air in the caisson is made possible by means of a tubular passageway which leads to the bottom of the caisson.

When a workman wishes to enter the caisson, he first goes into the tube through an upper door, which is tightly closed after his entrance. Air is then forced into the tube or "air lock" until its pressure is equal to that in the caisson. He then opens the doors leading to the caisson, and enters, closing the doors behind him. When he emerges from the caisson, the process is reversed. In practice it is found necessary to allow a man to remain in the air lock for some time, while the air pressure is slowly increased or decreased, in order that he may not suffer from too sudden change of pressure.

FIG. 5. A lighthouse upon a submerged foundation

The foundation was constructed by men who worked under water

Compressed air is used also for excluding water in excavating tunnels beneath water level. The principles involved in excavating tunnels are similar to those of the caisson. Diving bells are also used when men work under water. The use of compressed air in raising torpedoed ocean vessels gives promise of making it possible to regain immense quantities of lost property.

7. Weight of air. Not only is air like other substances in occupying space but, like them, it has weight. The best way to show that air has weight is to weigh a quantity of it, as may be done in the following manner: The air (almost all of it) may be pumped from a brass globe or glass flask which is so constructed that it may be closed after the air has been removed. The closed vessel may then be placed upon a balance (fig. 6) and weighed. If the vessel is opened (thus allowing air to enter it) and again weighed, any difference in weight that is found will be due to the air which has come into the vessel. If we suppose all the air was pumped out in the first place, the increase in weight would be precisely the weight of the air the vessel contains. Therefore we may measure the vessel used and calculate the cubic contents, and thus find out the weight of the air per cubic foot or meter, as shown by the experiment. This result will not be quite correct, since not all the air can be removed from the vessel by the pump, and therefore we include part of the air in both weights. Is our result greater or less than the true weight of air?

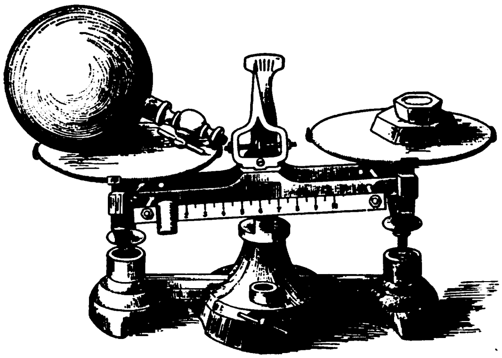

FIG. 6. Weight of air

The globe, which was balanced after part of the air had been pumped from it, was found to be heavier when the air was again allowed to enter it

By attaching a barometer (sect. 9) to the air pump it is possible to find out what fraction of the air was left in the vessel, and this enables us to tell exactly what relation the amount of air removed by the pump bears to the whole

amount of air in the flask. By this means we may ascertain the necessary corrections and discover the true weight of air. This has been done many times. The actual weight of air varies from time to time, because of changes in temperature, moisture, and pressure, but at 60° F. it is about 34.5 grams per cubic foot.

8. Air pressure. If air has weight, it ought to press down upon the surface of the earth just as other objects do when they rest upon the earth, and it ought to rest upon us and other objects on the earth's surface with considerable weight. The truth of this may be tested in the following manner: A bladder glass (fig. 7) may be placed upon the stand of an air pump, with a sheet of rubber tied over the open top. If there is any pressure upon the top, due to the weight of the air, it does not push the rubber downward, because the air within the glass resists, as it does in the football or the tire. If, however, the air is partially removed from the interior of the glass by the use of a pump, the resistance from within is reduced, and the rubber is pressed downward and may even be broken. It is plain that there is pressure upon the upper side of the rubber, but that so long as the air was allowed to remain in the glass the pressure upon the two sides was equal.

FIG. 7. Air pressure

When air is pumped from within the glass jar, the sheet of rubber tied over the upper, open end of the jar is forced downward by the weight, or pressure, of the outside air

9. Measurement of air pressure by barometers. The pressure gauge discussed in section 5 is one device for measuring air pressure. It may also be measured by use of instruments known as barometers. There are two principal types of barometers — the aneroid barometer and the mercurial barometer.

Let us consider the aneroid barometer first (fig. 8). The part of this instrument which is sensitive to the air pressure is a small, thin-walled metal box shaped somewhat like the case of a watch. The air is exhausted from this metal box and it is sealed air-tight. The pressure of the air tends to press the flat top and bottom of the metal box inward, as it did with the rubber top of the bladder glass, but the metal does not yield nearly so much as the rubber did. In fact, the metal bends so little that it is not easy to see the change taking place. For this reason an arrangement of levers or gear wheels which will magnify the motion is attached to the box and operates a pointer which moves up or down as the pressure increases or decreases. A still larger movement is secured in a compound barometer of this type, which is constructed by joining six or eight of the metal boxes (fig. 11, *A*).

Fig. 8. A pocket aneroid barometer

This type of barometer is graduated so as to show both the pressure and the elevation at which a reading is taken

The mercurial barometer is quite a different instrument. Indeed, at first it appears to have no resemblance to the aneroid. A simple mercurial barometer may be constructed in the following manner: Secure a glass tube about three feet long, with one end closed. Fill it with mercury, close the open end with the finger, invert the tube, and place the

open end in a cup of mercury. When the finger is removed, the mercury in the tube will not continue to fill the whole tube but will fall so that the top of the mercury column is about thirty inches above the mercury in the dish (fig. 9). If this column of mercury is observed from time to time for several days, it will be found to rise or fall slowly. The change in height of the column is due to the change in pressure of the air.

FIG. 9. A simple barometer

The weight of the air holds the mercury in the hollow glass tube. Any change in the weight of the air changes the height of the column of mercury

10. Graduation of the barometer. In order to be an efficient instrument a barometer must be graduated; that is, a scale of some kind must be attached to it in such a way that the movements of the pointer or of the top of the mercury column may be easily read and recorded (fig. 10). This scale might be marked in pounds pressure per square inch, and this would seem a very natural thing to do, but it is not the common method. Mercury barometers were the first used, and usually we express air pressure by stating the height of the column in a mercury barometer. These barometers are therefore graduated in inches or centimeters, and a scale of this sort will be found upon any practical instrument for measuring air pressure. An aneroid barometer is commonly given a scale so graduated that the numbers correspond with the readings of the mercury barometer, and therefore the readings of the two are identical.

Since the air pressure decreases with increase of elevation, barometers may also be graduated to read in terms of the elevation above sea level. Aneroids are frequently so graduated.

Since their small size makes it possible to carry them conveniently, they may be used to ascertain the approximate height of mountains and the elevations reached by balloons or aëroplanes. Some aneroids are so constructed that a pen attached to the pointer is caused to write on a piece of paper which is kept moving by means of a clock in such a manner as to make a record of the readings. Such an instrument is called a *barograph* (fig. 11).

11. Altitude and air pressure. It was stated in section 8 that the pressure of the air is due to the weight of the air above. It must be plain that if we ascend in a balloon, we are leaving some of the air below us, and the pressure of the air at our elevation will be less by a proportionate amount. In the case of our bladder-glass experiment, if the experiment were conducted at a place 1000 feet up in the air, as in a balloon, the rubber would be pressed down by a force equal to the weight of the air *above* it; but there would be 1000 feet less depth of air above it than there would be if it were at the earth's surface, and the pressure would be correspondingly less. The same thing would be true on a mountain 1000 feet high, as has been noticed by those who have ascended mountains. It is this fact which makes it possible to use the barometer to measure altitudes (fig. 12).

It is not possible to state any exact rule as to the pressure which will be found

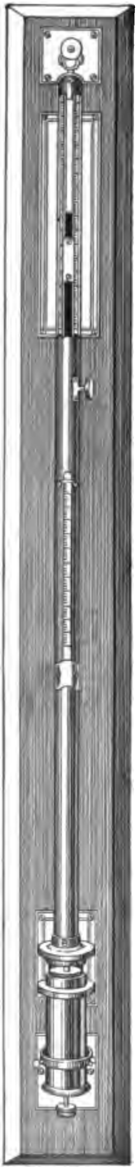

FIG. 10. A standard barometer

A mercurial barometer with thermometer and scales. The graduations allow both barometer and thermometer to be read. This is the standard form of barometer used by the United States Weather Bureau

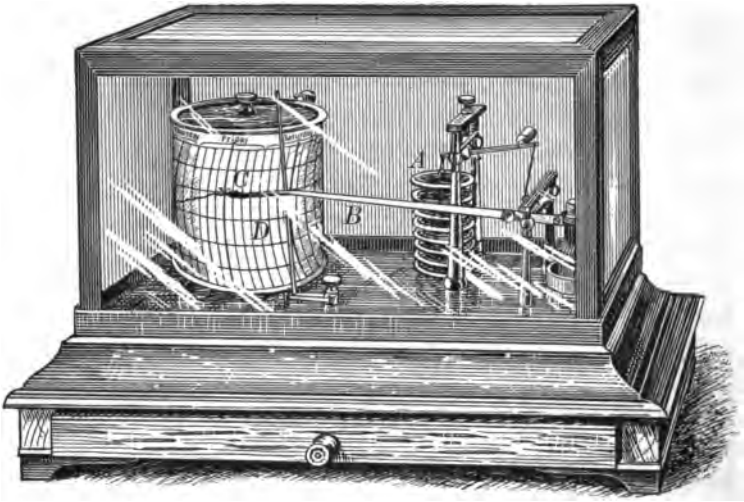

FIG. 11. A barograph

This instrument automatically records the air pressure. *A*, compound aneroid barometer; *B*, pointer, at the tip of which is *C*, the pen; *D*, paper-covered cylinder which is rotated by a clock contained within it. As the pressure changes, the pen moves up or down, thus tracing its course upon the rotating cylinder of paper

at any given altitude, but at elevations of less than a mile above sea level the pressure decreases by an inch for each 900 to 1000 feet increase in altitude. The average pressures for various elevations are shown in the following table:

ELEVATION	PRESSURE	ELEVATION	PRESSURE
Sea level . . .	30 inches	7010 feet . . .	23 inches
910 feet . . .	29 inches	8150 feet . . .	22 inches
1850 feet . . .	28 inches	9330 feet . . .	21 inches
2820 feet . . .	27 inches	10,550 feet . . .	20 inches
3820 feet . . .	26 inches	13,170 feet . . .	18 inches
4850 feet . . .	25 inches	16,000 feet . . .	16 inches
5910 feet . . .	24 inches		

12. Effect of temperature. It is often noticed that a pneumatic tire which is only moderately firm in the morning, when the bicycle or automobile is first taken upon the road,

may be much harder by noon, as if more air had been put into it. The same thing will occur if the machine is allowed to stand in the sun. The additional pressure may, indeed, become so great as to burst the tire. Of course it is very clear that no air has been added to that which was in the tire in the morning, for if the rubber will retain the air which is in the tire, it will be equally effective in preventing

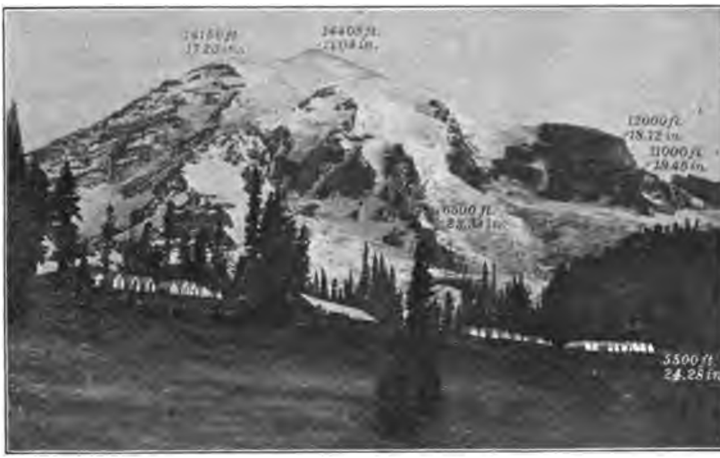

FIG. 12. Air pressures at different elevations

The illustration shows Mt. Rainier, Washington, from 5500 feet to the summit. The figures show the elevations at different points and the air pressures at these points. Note the decrease of air pressure with the increase of elevation

more from entering. Since such an increase of pressure as we have been describing occurs only when the tire has been heated by contact with the hot road or by direct exposure to the sun, it is fair to conclude that when the air is heated it has greater tendency to expand and that it therefore presses harder against the walls of the tire and would expand if it were not confined by the tire.

The notion that air expands when heated ought to be tested before we accept it finally. This may be done in

many ways. For instance, an empty bottle may be inverted and its mouth placed under water, and the bottle warmed by holding it between the hands (fig. 13) or by using a flame. The air will soon be warmed, and if it expands, bubbles of air will overflow from the mouth of the bottle and rise to the surface of the water. What other ways can you devise to test the notion that air expands when heated?

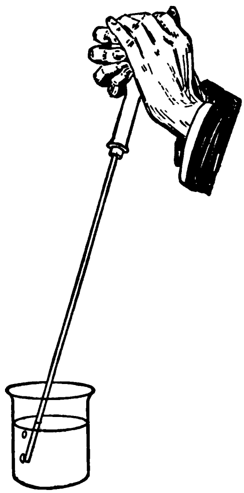

FIG. 13. Expansion of air

When heated by the hands the air in the flask expands, and bubbles of air appear at the open end of the tube under the water

13. Thermometers. Air expands when heated and contracts when cooled. It is possible to arrange apparatus in such a way that this expansion may be observed and measured. An instrument by means of which such measurements could be made would give us some idea of the degree of heat. It would, in fact, be an air thermometer. Such thermometers have been constructed and used, but only for special purposes. For ordinary purposes much more satisfactory thermometers are made from other substances.

Thermometers such as are in common use depend upon the expansion and contraction of a liquid. The liquid most commonly used is mercury, though alcohol which has been colored red or blue is sometimes used. Each thermometer is furnished with a scale of degrees by means of which the temperature may be read. There are two sorts of scales in use in this country (fig. 14). The one in most common use is called the Fahrenheit scale, after the man who designed it. On this scale the freezing point of water is 32° and the boiling point is 212°. The centigrade scale, which is the one used in all scientific work the world over, places the zero mark at the freezing

point of water and the 100° mark at the boiling point of water. Because there are two scales, it is always necessary, when we write temperatures, to indicate which scale is used, and thus we say that the boiling point is at 100° C. or 212° F. Since both types of thermometers are in use, it is important to be familiar with both of them and to be able to determine the equivalent of a given reading of one thermometer in terms of the other type of thermometer.

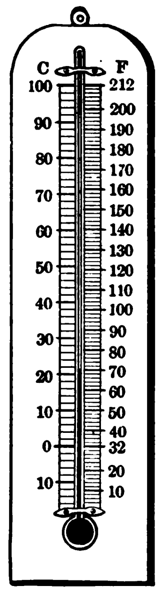

FIG. 14. A mercurial thermometer

Both Fahrenheit and centigrade scales are shown

In the Fahrenheit scale the freezing temperature is 32° above zero and the boiling temperature is 212° above zero. Therefore there are 180° between freezing and boiling, according to the Fahrenheit system. In the centigrade system the freezing temperature is zero and the boiling temperature is 100°. Therefore 100 divisions on the centigrade scale equal 180 divisions on the Fahrenheit scale. One centigrade degree equals 1.8 Fahrenheit degrees. A temperature of 80° C. is equivalent to $80 \times 1.8 + 32$, or 176° F.

14. Some effects of expansion. It was learned in a previous experiment that if the air in a bottle is heated, the mouth of the bottle remaining open, the air will expand and some of it will escape. The air that remains fills all the space that the whole amount originally occupied, but plainly it cannot weigh the same, for only a part of the original air is in the bottle, and a part cannot weigh as much as the whole. Careful measurement and weighing will show that the weight of the bottle is less by exactly the weight of the air which has escaped. We usually express this by saying that heated air is lighter than cold air. We must remember, however, that

this is true only under certain conditions. For instance, if we put a stopper in the bottle so that there can be no expansion and therefore no escape of air, after heating the bottle we shall have all the air that was in it at first, and it will weigh exactly the same. As stated before, if we allow the bottle to remain open some of the air will escape, owing to expansion, and at the second weighing we shall be weighing only a part of the air that we had at the first, and hence the weight will be less. It would be better to say that heated air is lighter than cool air if we take equal volumes under the same pressure.

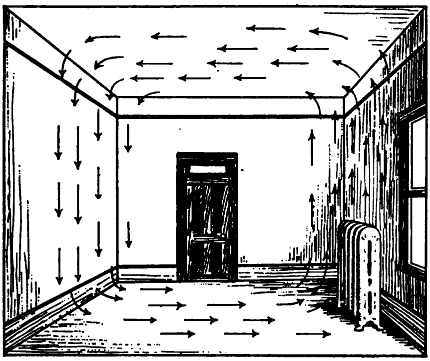

FIG. 15. The circulation of air

Diagrammatic representation of the circulation of air in a closed room heated by a radiator

15. Convection currents. The fact that warm air of a given volume and pressure is lighter than cold air of the same volume and pressure explains many common occurrences. Almost everyone has noticed ascending currents of air over a radiator or stove. These currents are strong enough to carry upward light objects, such as bits of paper, and to cause pinwheels to revolve. When the air reaches the top of the room, it flows along the ceiling toward the more distant parts of the room, and as it becomes cooler it may descend again (fig. 15). Its course may be easily traced if it is mingled with smoke. Less commonly we notice that air is flowing along the bottom of the room from all sides toward the source of heat (radiator or stove). One may find these bottom currents very easily if he will hold a burning match or candle near the floor in the vicinity of a heated stove or radiator and note the direction

in which the flame is blown. Their course can be traced also by adding smoke to the air. The air is always in circulation in a room containing a heated stove or radiator. Since the air in the vicinity of the source of heat is lighter, volume for

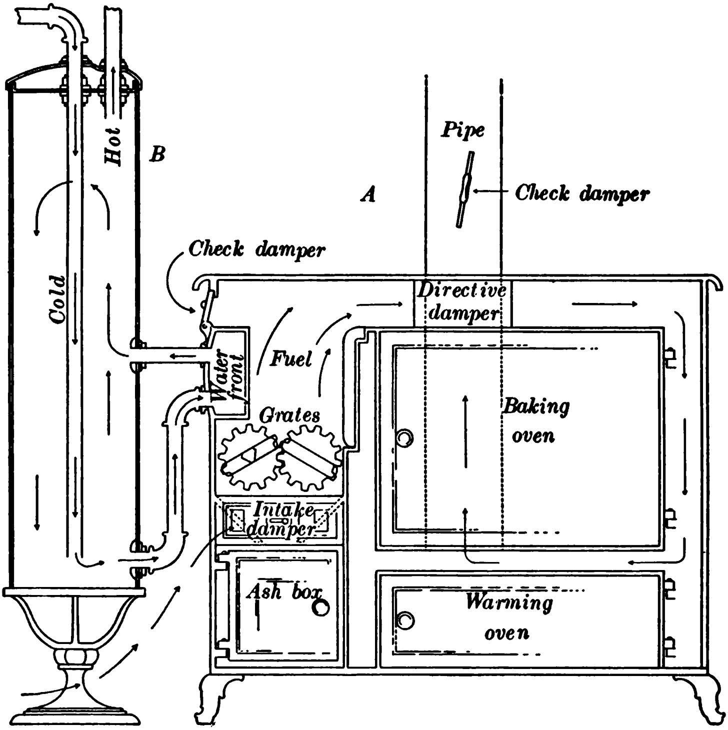

Fig. 16. Diagram of cookstove and water heater

Trace the air currents through the stove and the water currents through the heater

volume, than that in the other parts of the room, it follows that the lower air near the stove does not have so much weight resting upon it as does that in other parts of the room. It is therefore pushed upward and finally reaches the ceiling, when it spreads out, is cooled, and descends slowly

in the cooler parts of the room, only to flow across the floor toward the source of heat, where it will again be warmed and be pushed up. Thus the circulation continues. Currents of air that are caused by differences of temperature, such as the currents of which we have been speaking, are called convection currents.

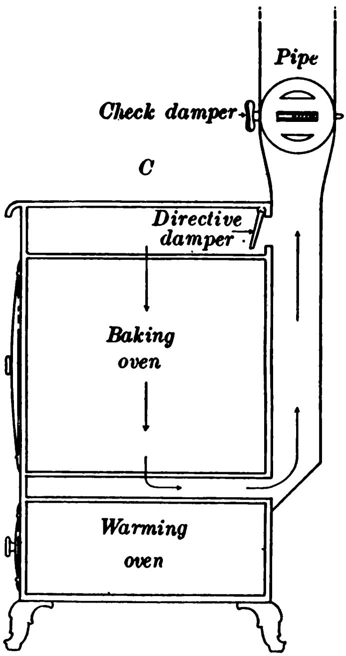

FIG. 17. Diagram showing end view of cookstove shown in figure 16

16. Stoves, furnaces and water heaters. The circulation of air in hot-air heating apparatus such as is commonly used in private houses is maintained by convection currents. The heater is located in the lowest part of the house, usually the basement, and is surrounded by a jacket which incloses a heating chamber. Cold air is admitted to this chamber from outdoors through a large pipe, is expanded by heating, is pushed up through the pipes leading from the top (Why?) of the air chamber to the various rooms of the house, and escapes out of doors through available openings. In some cases the apparatus is so arranged as to take cold air from within the house, as from the front hall, instead of from without, but this arrangement is not desirable except as an emergency device in exceptionally cold weather. In the latter case the same air is passed through the rooms repeatedly, while fresh air from outdoors is desirable. The movements of hot and cold air and water are well shown in cookstoves and water heaters (fig. 16).

It will also be found of interest in this connection to determine the reason for the circulation of water in the hot-water pipes by which a building is heated.

17. Chimneys. The main purpose of a chimney is to supply a draft; that is, to cause the air to pass rapidly through the

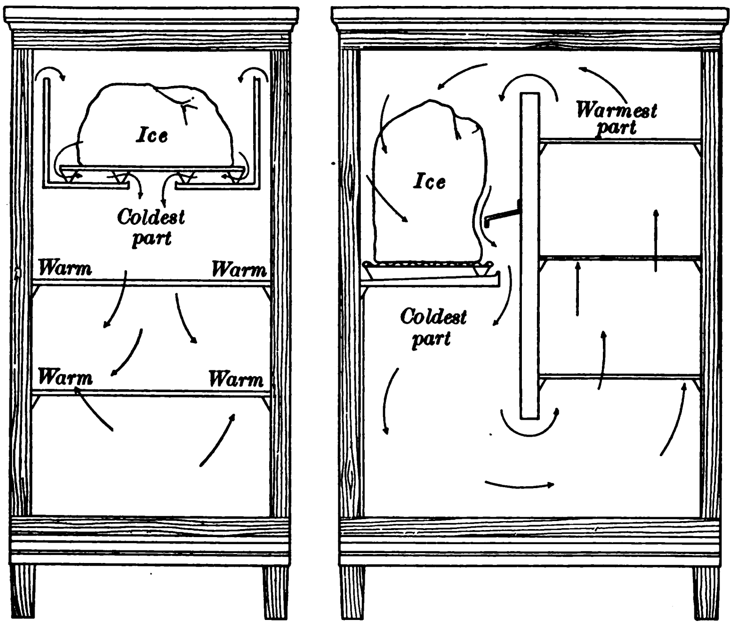

Fig. 18. Diagrams of two types of refrigerators

Air passes downward over the ice to the bottom of the box, then upward and back to the ice again. Where should articles be placed to be kept at lowest temperatures?

fire and make it burn more vigorously. The chimney must also remove the smoke. Since the air in the chimney is heated, it is not so heavy as the outside air. The outside air therefore pushes through the furnace into the chimney and crowds the warmer air upward with sufficient current to enable it to carry the smoke with it. But the incoming cold air is heated as it passes through the fire, so that it is lighter than the

outside air and is in turn forced upward. The movement of the air is therefore continuous.

18. Air currents in refrigerators. Some of the most important devices of modern times relate to preservation of food by use of low temperatures, a subject which is later discussed in connection with dangers of destruction of surplus foods Some of the principles of refrigeration are shown in figure 18, this topic being more extensively discussed later in this book. If in your shop work you will build an ice box or refrigerator by use of the principles shown in the illustration, you will probably find the experience of value to you during the rest of your life.

19. Importance of air temperature. The temperature of the air is a matter of importance to us all. It has much influence in determining whether our sports shall be tennis, golf, and baseball or coasting and snowballing; it decides for us whether the water shall invite us to swim or to skate; it even settles pretty largely the kind of clothing we shall wear, the food we shall have to eat, and the social activities in which we shall engage. It levies a tax upon us for coal at one time and for ice and electric fans at another. Our whole round of activities in business and pleasure is very largely regulated by the temperature of the air and the seasonal changes. The more fully we understand air currents and the temperature of air and other substances about us, the more fully we shall be able to regulate these things to suit our needs.

CHAPTER II

AIR AND WATER

20. Questions for Discussion. 1. Why do clothes usually dry better on warm days than on cold days? 2. Which can endure the higher temperature, the man who perspires a great deal or the one who perspires but little? 3. Why do drops of water appear on cold-water pipes on some summer days and not on others? 4. Why do these drops form most abundantly when cold water is running through the pipes? 5. Why are grass and other plants often moist in the morning although no recent rain has fallen? 6. Why does frost form on windowpanes in winter? 7. What are the conditions necessary to the deposit of dew? 8. How does the practice of flooding cranberry bogs help to protect the cranberries against frost? 9. Why does the air feel more invigorating on a clear day than on a damp day even though it is cool? 10. Why does hot weather in Kansas produce less discomfort than weather of the same temperature ordinarily would in New Jersey? 11. Why are "muggy" days so oppressive? 12. A student of school hygiene asserts that the air in the ordinary American schoolroom is like the air of the desert. What causes this condition, and how can it be prevented? 13. In what ways is the air of your schoolroom unlike the air of the desert? 14. What improvements, if any, are needed in the air of your schoolroom? 15. Do snow and ice evaporate during cold winter weather?

21. Evaporation. It is a matter of common observation that if water is left exposed to the air, it soon disappears. We say that it has evaporated. This does not mean that it has gone out of existence. It has only changed into the form in which it is invisible and can pass into the air. It has become a gas. The same thing is true of the surface of every pond, lake, river, sea, and ocean — indeed, of any water that is exposed to the air. There is, therefore, always considerable water in the atmosphere, and so long as it remains in the form

of a gas (water vapor) it is invisible, just as is true of the remainder of the atmosphere.

22. Condensation. Not only does water readily disappear into the air but it sometimes makes its appearance more or less mysteriously at a point where previously there has been no water. Thus it is a common observation that if a glass pitcher which has been carefully dried on the outside be filled with ice water, the outside of the pitcher may soon become moist. Sometimes one is inclined to account for the phenomenon by supposing that by some means water has got out of the pitcher to the outside. A little reflection shows that this cannot be the explanation, since the same thing will occur to a cold piece of metal if it is brought into the room; also those who wear eyeglasses are annoyed by the moisture which collects on their glasses when they go from cold air out of doors into warm living rooms. Indeed, if the ice water were inclosed within a tightly stoppered bottle instead of being exposed to the air in an open pitcher, the collection of moisture would be in no wise interfered with. Out of doors, at night, water commonly collects on cold objects, and sometimes the air itself becomes filled with a fog consisting of minute floating particles of water. All of these phenomena may occur quite independently of any visible source of water, such as a pond or lake.

We must therefore conclude that the water which appears upon cold objects probably comes from the air, just as the water which evaporates goes into the air. We may conclude also, since it appears, or condenses, only upon objects relatively cooler than the air, that the temperature has something to do with it. But these conclusions, even if verified by other experiments, do not solve all the problems connected with the deposition of water on the pitcher. Why is not water always condensed upon the outside of vessels containing ice water? Is it because there is at times little water in the air or no water at all or because of uniform temperatures?

23. Amount of water in the atmosphere. It has been estimated that the water in the atmosphere of the earth would, if condensed into liquid water, make a layer at least an inch deep over the whole surface of the earth. The amount of water in the atmosphere in the form of vapor, or gas, varies greatly at different times and places. These differences are significant in many ways, for the amount of water in the air is an important factor in producing such things as cloudy and clear days, rain, dew, fog, snow, and the discomfort that we have upon warm, muggy days in summer.

An illustration will help to show what controls the amount of water vapor present in the atmosphere. Suppose that a small quantity of water is placed in a dish within an air-tight chamber. We know that the water will immediately begin to evaporate, but it will not all evaporate. The space in the chamber will soon contain all the water vapor that it is able to contain under existing conditions, and evaporation will then cease. The space within the chamber is said to be *saturated* with water vapor when it contains all that it is able to contain. If the chamber is warmed, however, an additional amount of water will evaporate, while if it is cooled, some of the water vapor will return to the liquid form and may be seen upon the walls in the form of drops.

It thus appears that the water evaporates into the adjacent space until the space is saturated and that the amount of water which is needed to saturate a given amount of space depends upon the temperature. The exact amounts of water in grams per cubic meter of saturated space are given for reference in the table in section 25. The amount of air in the space has no influence on the amount of water vapor which the space is able to contain.

24. Moist and dry air. The space about us is not often saturated with water vapor. Among the reasons for this may be mentioned the fact that in many parts of the world there is not much water exposed and therefore not much

opportunity for water to evaporate. Even where there is much water exposed, as at the surface of lakes and oceans, the space above the water is not usually saturated, though it contains a large amount of water. For instance, a space to-day may contain half as much moisture as would be possible at the present temperature, while to-morrow it may contain only a third as much as would be needed to saturate it without changing temperature; that is, in the first case the space may be said to be one half saturated and in the second case one third saturated. These relations are usually expressed in percentages. When saturated, the space contains 100 per cent of the moisture that it is able to contain without change of temperature; if only half the possible amount is present, the percentage is fifty; and similarly for other values. This percentage expresses the *relation* between the water actually present and the amount which the space would be able to contain. This relation is called the *relative humidity.*

The actual amount of water present in a given space is known as its *absolute humidity* and may be measured in grams per cubic meter. Absolute humidity therefore refers to the amount of water actually in the air, and relative humidity refers to the relation between the amount of water actually contained and the total amount which might be contained at the same temperature.

25. Reference table of the amount of water in one cubic meter of saturated air at given temperatures. In this table the temperatures are given in both centigrade and Fahrenheit scales. In this and succeeding work students should practice thinking in both systems of temperature measurements, since the Fahrenheit system is in common public use, and the centigrade system in general use in science and likely to become more common in public use.

Absolute humidity and relative humidity can be the same only when the amount of water actually in the air is the full

amount that the air can contain at that temperature. For example, a cubic meter of air at 16° centigrade (60.8° F.) might contain 13.50 grams of water. If we find that it actually does contain 6.75 grams (absolute humidity), it has one half, or 50 per cent (relative humidity), of the amount of water it might contain when fully saturated.

Temperature		Amount of water in grams	Temperature		Amount of water in grams
C.	F.		C.	F.	
0°	32°	4.84	20°	68.0°	17.12
1°	33.8°	5.18	21°	69.8°	18.14
2°	35.6°	5.54	22°	71.6°	19.22
3°	37.4°	5.92	23°	73.4°	20.35
4°	39.2°	6.33	24°	75.2°	21.54
5°	41.0°	6.76	25°	77.0°	22.80
6°	42.8°	7.22	26°	78.8°	24.11
7°	44.6°	7.70	27°	80.6°	25.49
8°	46.4°	8.21	28°	82.4°	26.93
9°	48.2°	8.76	29°	84.2°	28.45
10°	50.0°	9.33	30°	86.0°	30.04
11°	51.8°	9.93	31°	87.8°	31.70
12°	53.6°	10.57	32°	89.6°	33.45
13°	55.4°	11.25	33°	91.4°	35.27
14°	57.2°	11.96	34°	93.2°	37.18
15°	59.0°	12.71	35°	95.0°	39.18
16°	60.8°	13.50	36°	96.8°	41.3
17°	62.6°	14.34	37°	98.6°	43.5
18°	64.4°	15.22	38°	100.4°	45.8
19°	66.2°	16.14			

The relative humidity of the air over the surface of the earth varies widely. As an average the relative humidity over the land is about 60 per cent, and over the ocean it is about 85 per cent. But variations from these averages are so great that the averages do not tell us much about any given day or given locality. If the relative humidity is low, we say the air is dry; if the relative humidity is high, we say the air is moist, or "muggy."

26. Saturation and the dew point. If the temperature falls below that at which the contained vapor saturates the space, some of the water will condense into the liquid form. For instance, if the space in a room is at a temperature of 22° C. (71.6° F.) and contains 10 grams of water vapor to the cubic meter, the air will appear rather dry, for it would be able to contain over 9 grams more without being fully saturated. If, however, the room were cooled to 5° C. (41° F.) its capacity would be decreased to less than 7 grams per cubic meter. Some of the water would therefore condense into the liquid form and settle upon surrounding objects. In the case supposed how much would condense? (See sect. 25.)

The temperature at which a given space would be saturated by the water that it contains and below which the water will begin to condense is called the *dew point.* What was the dew point in the above example?

In the example used above, when the air was at the temperature of 22° C. and there were 10 grams of water per cubic meter, what part did the room actually contain of the total amount that it would have been able to contain? Express your result in the form of a fraction; also in the form of a percentage.[1] Is this relative or absolute humidity? If the room contained all the water that it could contain without a change in temperature, what would be the relative humidity? What is the relative humidity at the dew point?

Relative humidity is of much more interest to us than absolute humidity. Whether the atmosphere feels dry or moist or whether clouds are seen (fig. 19) depends upon what proportion it has of the water it is able to contain (that is, upon how near the relative humidity is to 100 per cent), and we are much more concerned with the way the

[1] There is a slight error in this method, since no allowance is made for contraction due to cooling. Exact work would require that the proper correction be applied, but the error is so slight that it is immaterial for present purposes and will be disregarded.

atmosphere feels and the probability of moisture condensing in the form of rain than we are with the number of grams of water in a cubic meter.

27. How to determine whether the air is moist or dry. If one wishes to know whether the air of a room or the air out of doors is relatively moist or dry, he may form some

FIG. 19. A cumulus cloud

This kind of cloud is formed by the condensation of moisture in columns of rising air. Note the characteristic lower edge of the cloud, indicating the level at which the dew point is reached

opinion about it by noting the way it "feels"; but opinions are inaccurate. Again, one may make use of the ice-water pitcher, and this will give him more accurate information. Thus, if the air contains relatively large amounts of water, the condensation upon the pitcher will be more abundant and will appear more quickly after placing the water in the pitcher than would be true in a dry atmosphere. Thus one

may be able to estimate roughly the relative moisture of the air and the consequent probability of rain.

If more accurate information regarding the relative moisture of the air is desired, in order that it may be expressed in figures for record or comparison, a more carefully designed experiment is necessary. In the previous statements about absolute and relative humidity the figures used had been previously determined. If we wish to know the relative humidity of a schoolroom or room at home, we shall need to find out both the absolute and the relative humidity.

A common experimental procedure for ascertaining the amount of water in the air is as follows: Water is placed in a bright metal cup, ice is added, and the whole is stirred in order that the water may be evenly cooled. In a short time water will be deposited on the outer surface of the cup in a thin film, and as time passes it may accumulate in drops, as it does more familiarly on a pitcher containing ice water. This water has been deposited from the air because the space about the cup is cooled by the cold metal until its capacity for water vapor is less than the amount of such vapor present. Some of the water vapor therefore condenses into the liquid form and is seen on the surface of the cup. At the moment when the first trace of moisture appears upon the surface of the cup the adjacent space is evidently saturated; that is, the temperature close to the cup is that at which the water vapor present saturates the space.

We now know the temperature, which for illustration we will suppose is 10° C. (50° F.), to which this particular body of air or any part of it would all need to be reduced in order for it to be at the saturation point. By reference to the table in section 25 we find that at this temperature saturated air contains 9.33 grams of water per cubic meter. This, then, is the absolute humidity of the room. However, the room thermometer shows the room temperature to be 20° C. (68° F.), and our table shows that air at this latter temperature at

saturation point contains 17.12 grams of water per cubic meter. Therefore we need to determine what per cent 9.93 is of 17.12. It is 57.4 per cent, so 57.4 per cent is the relative humidity. By use of this method it is possible to determine with approximate accuracy the humidity of any room or of the open air at any time.

28. Variations in relative humidity. If the temperature changes, the relative humidity changes also. For instance,

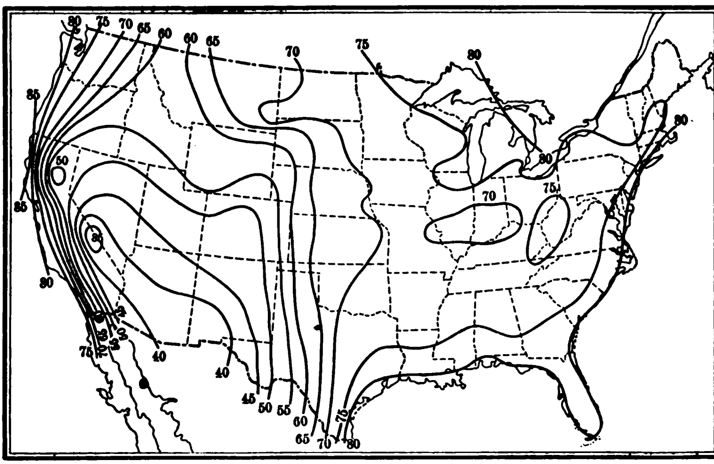

FIG. 20. Average relative humidity in the United States

The figures show relative humidity in percentages. After diagram by H. J. Cox

a space which is saturated at one temperature may have its relative humidity reduced very greatly by a temperature increase of a comparatively few degrees. In the same way the relative humidity changes during the day as the temperature rises and falls. It also changes because of difference in the actual amount of water present — absolute humidity. In most parts of the United States (fig. 20) where it is not desert the relative humidity in summer averages not less than 65 per cent; in the desert region of the Southwest it

may average below 30 per cent; and there is a record of relative humidity as low as 3 per cent at Yuma, Arizona, though this very low humidity did not last more than a few hours.

29. Humidity in houses. In the winter the air of our houses is heated so that it is much warmer than the air out of doors. Usually no water, or very little, is added, and therefore the air seems very dry; that is, the relative humidity is very low. It is usually below 50 per cent and sometimes as low as 20 per cent.

During the winter those persons who spend most of their time in the house are usually living in a desert climate as far as atmospheric moisture is concerned. Various devices have been suggested to remedy the condition of low relative humidity. Some people allow a dish of water to stand in the living room. Small tanks of water are placed upon the backs of radiators, and most hot-air furnaces have tanks containing about two gallons of water so placed that the water will evaporate and pass into the rooms. Experiments to determine whether these devices are effective have failed to show much gain in humidity from their use. The gain from the furnace tank was shown to be about 1 per cent. Even with specially constructed furnaces which evaporate from 12 to 15 quarts per day the results were not so good as desired. In one experiment it was possible by special effort, in very cold weather, to evaporate from 20 to 24 quarts per day. In this last case the relative humidity was raised to 35 per cent at a temperature of 20° C. (68° F.). No device has yet been invented which is entirely satisfactory in keeping dwelling houses and schoolhouses as humid as they should be. Steam jets in the boiler room from which air passes into schoolrooms have proved fairly satisfactory.

30. Humidity and health. Although a relative humidity of 35 per cent seems low, it has been noted that such a condition is highly acceptable in winter time, since most

dwelling rooms ordinarily are very much below that point. Air which is continuously hot and dry does not provide a healthful environment. Persons who live in such air are restless, often sleep poorly, and the sensitive membranes of nose, ears, and throat become dry and parched, thus rendering the possessors more susceptible to cold infections. Furthermore, such persons are affected by cold temperatures more readily and more seriously than are others, since in the dry air the skin evaporates water more rapidly and produces the cold feeling. Such persons often urge higher temperatures when lower temperatures and higher relative humidity are what they usually need. Tightly closed, highly heated, relatively nonhumid houses are disease breeders, while average temperatures, open windows, and abundant moisture and fresh air predispose toward good health.

CHAPTER III

AIR TEMPERATURES AND THE SEASONS

31. Questions for Discussion. **1.** Is your distance from the sun the same in the morning and at noon? **2.** Would any difference in your distance from the sun at morning and at noon have any important effect upon the temperature? **3.** How can you account for differences in temperature between morning and noon, and noon and evening? **4.** What changes in air temperatures might make it difficult for a balloonist to keep his balloon afloat at night? What adjustments could he make so as to keep afloat at the same elevation? **5.** Why is it not warm at the north pole during the season of long days in that region? **6.** What differences are there in the length and intensity of shadows of objects or persons at noon, in the early morning, and in the later afternoon? How are these differences explained? **7.** If we have two adjoining sections of level farm land from which wheat has just been cut short, and plow one field so that the soil is finely pulverized, over which field will the air be hotter during July and August? **8.** In southern Texas corn may sometimes be planted in February; in Oklahoma, in March or April; in Iowa, in April or May; in Minnesota, in June or early July. Why is there this seasonal progression in corn planting? Why is it not possible to grow the same kinds of corn in all these regions? **9.** Why cannot corn be grown in most parts of Canada? **10.** What are the relative advantages and disadvantages of the daylight-saving legislation?

32. How the air is warmed. It does not usually occur to most people that the presence of the earth's atmosphere has a great deal to do with its temperature. In a later section of this book it will be shown that astronomical bodies, as the moon and others, cannot have as even temperature as the earth, because these bodies do not possess atmospheres. However, the air itself does not get much warmth directly from the sun's rays, even though the rays pass through it. The air is relatively transparent, and both heat and light

pass through it with very little hindrance. This may be illustrated better by the more familiar case of the sun's rays passing through glass. If the glass of a window is perfectly clean and transparent, the sunshine will pass through it and warm the room within, but the glass is not much warmed. If it is covered with dust and other substances which hinder the passage of the sunshine, the window is somewhat warmed and the room is heated and lighted less. In the same way the transparent air gets little warmth from the sun's rays which are passing through it, excepting as the heat is absorbed by dust, clouds, and water vapor. When the earth has been warmed, the lower layer of air is warmed by the earth. Being lighter, it is replaced by cold air, the whole body of air being warmed more or less in this way. The temperature of the air therefore depends principally upon the temperature of the area over which it is moving, whether this area is land or water.

This explains why it is that in summer a wind which is coming across a large body of water is cooler than one which comes across the land, for in summer the water is cooler than the land. In the winter the reverse is true. In the same way a wind from the north is likely to be colder than one from the south.

When the sun is not shining directly upon a part of the earth, as at night or on a cloudy day, the earth's surface is continually losing heat to the surrounding space and therefore becoming cooler. That the heat which passes off from objects upon the earth warms any transparent medium through which it passes much more than it does when the sun's rays pass through such a medium is well illustrated by a greenhouse. Here the rays of the sun pass through the glass with little loss, but the heat which is given off by the objects in the greenhouse, after they have been warmed by the sun, does not easily pass through the glass. The heat is therefore retained in the greenhouse.

33. Seasonal changes of temperature. The change of temperature that comes with the seasons is to many of us the most notable and striking difference between the seasons. Why should there be such a difference? The sun still shines as brightly as ever, and its heat has not decreased in the winter. We are no farther away from the sun. Why are not our homes warmed as well by the sun in winter as in summer?

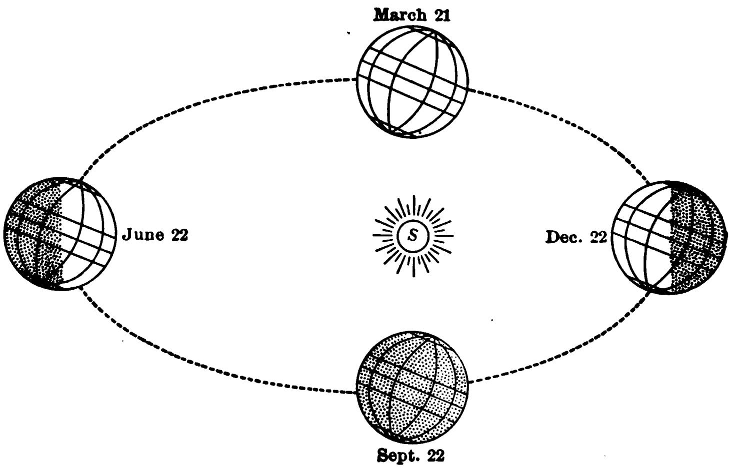

FIG. 21. The earth's orbit

Diagram showing the position of the earth with reference to the sun on four dates of the year

All apparent changes in the sun's position are due to the movement of the earth around the sun and to the inclination of the earth's axis (fig. 21). We often say that the sun rises and sets, when we know that these appearances are due to the motion of the earth. In the same way we say that the sun is higher in the heavens in summer than in winter, meaning that we have changed our position so that the sun appears higher. It is also noted that daylight lasts longer in summer than in winter.

We therefore know that as the seasons change there is also a change in the apparent altitude of the sun and in the length of day and night. It is to these changes that the seasons are due.

34. Effects of changes in the sun's altitude. Why should it make any difference in the heat that we get whether the sun is high up in the heavens or lower down near the horizon? We all know that it does make a difference, for we readily feel that the heat which we receive at noon in the winter and at noon in the summer are not the same. We notice the same thing when we compare the morning or evening effect of the sun with the effect at noon (fig. 22).

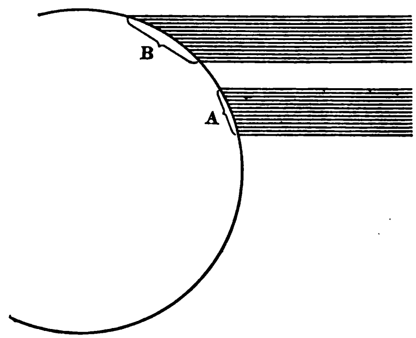

FIG. 22. Heating effects of the sun's rays

Diagram showing the difference in inclination of the earth's surface to the sun's rays. A sunbeam of the given size would cover more area at *B* than at *A*

The reason for this difference in the effect of the sun's rays is not difficult to understand if we make use of a simple experiment. Suppose in the morning, when the sun is not very high, we hold a piece of paper with a large hole in it squarely facing the sun and measure the spot of light which passes through the hole and appears on the floor or ground. At noon we do the same, making certain that the card is the same distance from the spot and also squarely facing the sun. It will be seen that the spot of light observed in the morning experiment was larger; that is, in the morning, when the rays of the sun were more aslant than at noon, the rays of light and heat that came through the hole covered a larger space on the surface of the earth than at noon, when the rays were more nearly at right angles with the earth's

surface. The light and heat coming through the hole might be the same in both experiments, but in the morning they are distributed over more surface and are therefore less intense. If you spread your butter over a larger piece of bread, it will be spread thinner.

Of course the difference that you have discovered between morning and noon exists between winter and summer. Can

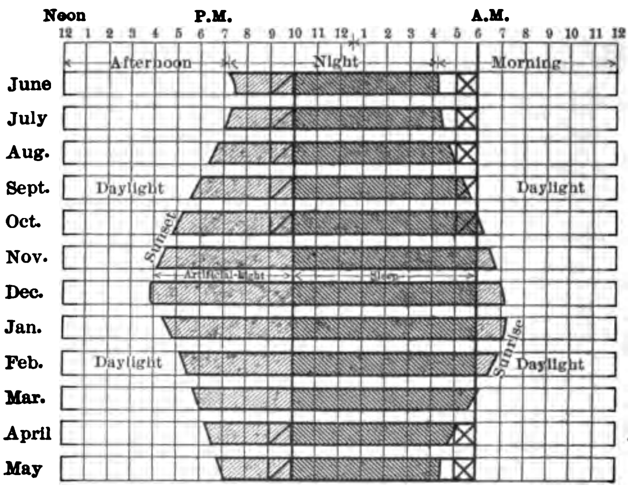

FIG. 23. Hours of light and darkness

The proportionate length of time the sun is above the horizon at a latitude of 40° N.; the time in which artificial and natural light are ordinarily used; and the effect of the daylight-saving legislation in which / is the time of artificial light now used for sleep and × the daylight redeemed from that previously used for sleep

you make a drawing showing exactly how large a space will be covered by a beam of sunlight one inch square if it comes to the earth at an angle of 65°? of 18°? In which case would the earth's surface receive more heat to the square inch? How much more? Which corresponds to summer? to winter?

35. Length of day and night. In summer, when the sun is higher in the heavens, it is also visible more hours in the day. The difference between the longest day and the shortest

is not the same at all places. It is least at the equator and greatest at the poles. At intermediate places the difference corresponds to the distance from the equator. In the central part of the United States (central from north to south) the longest daylight, in the latter part of June, is about fifteen hours, and the shortest, in the latter part of December, is about nine and one half hours (fig. 23).

The angle of the sun's rays and the number of hours during which it shines upon us work together to make the earth and the air warmer in summer than in winter. From the Government Weather Bureau reports and from other publications it is possible to find out the length of the day on the first of each month and to prepare a chart which shows the change in the length of the day during the year.

36. Daylight saving. During the past few years an active daylight-saving campaign has been developed. It is argued that the ordinary hours for professional and industrial occupations should be changed at different times of the year so as to utilize natural light more fully and to avoid the long unused-light period during summer when business hours begin at 8, 8.30, or 9 A.M. and daylight begins at from 4 to 5 A.M. The new legislation is not designed necessarily to lengthen the number of hours during which any one person works, but rather to leave more free time for leisure occupations. The opponents of the plan claim that no material advantage results from the legislation upon this question; that there is ample light during spring, summer, and autumn for a full day's work; that leisure hours can be arranged by those who desire them and can use them; that there is an irreducible amount of time needed for sleep, meals, and recreation upon which the plan may encroach.

CHAPTER IV

THE WEATHER

37. Questions for Discussion. **1.** Of what value are weather reports to your neighborhood and to the United States? **2.** Why is the air more invigorating after a severe thunderstorm than after a quiet rain? **3.** Why does the paper hanger find it warmer near the ceiling than near the floor? **4.** Is there pressure of the air against your face when the wind blows? **5.** How are low-air pressures and high-air pressures related to winds? **6.** What is a cyclone? a tornado? a storm? **7.** Why is it that in a tornado trees, houses, and other objects instead of being blown ahead of or out from the storm center are drawn toward it? **8.** How do fishermen generally judge when a storm is coming? **9.** What are the hot waves which sometimes sweep over great stretches of the Mississippi Valley? What causes them? **10.** By study of the rainfall map of the United States determine whether there is any relation between the regions of the greatest rainfall and the regions of greatest crop production. **11.** Is it of any importance to crops whether the rainfall occurs chiefly in a given part of the year or is distributed over the entire year? **12.** How does the United States Weather Bureau determine the amount of rainfall throughout the year in different parts of the country? **13.** Is snow counted as part of the rainfall? How is its amount measured? **14.** In your locality what are the months of greatest rainfall? Are these the months in which vegetation makes most growth?

38. General statement. Winds and rains come and go in an irregular way that makes it very difficult for us to feel any confidence in our plans if they are subject to disturbance by the weather. Weather signs are numerous in folklore. A number of them are the result of the experience of many years, while others are only the crudest superstition.

We have rain when there is a cause for rain; and the wind blows this way or that, depending upon certain causes. If we are able to discover and understand some of the causes of

all things connected with the weather, it will no longer be mysterious, and probably we shall be able to foretell it with certainty. Men have not yet been able to discover all the causes which are at work in the production of our weather, but enough have been discovered to make the science of meteorology one of greatest importance.

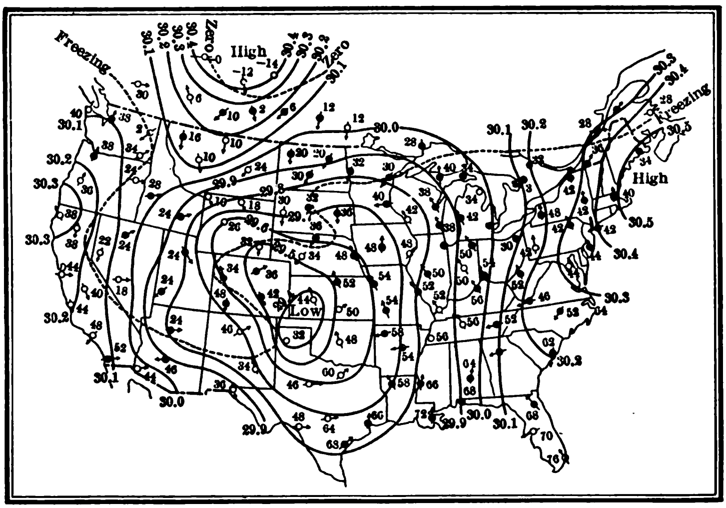

FIG. 24. Weather map for March 13, 1913

The three maps for successive days (figs. 24, 25, and 26) should be compared, to show the progress of the storm and the changes in weather conditions. The unbroken lines are the isobars; the arrows fly with the wind; the blackened circles indicate cloudy weather at the time of observation; the figures near the arrows show temperature; the broken lines are isotherms of zero and freezing temperatures. These figures are from the United States Weather Bureau

39. Air pressure and winds. The first thing we must study is the winds, for most other features of the weather depend upon winds. Winds are merely air in motion, and of course the faster the motion the harder the wind is said to blow.

In order to explain the cause of winds we must go back to the subject of air pressure and barometers. Anyone who has watched a barometer for several days knows that even

if it remains in one place, its indicator goes up and down, thus showing that the pressure is constantly changing. If we should secure a record of the readings of barometers at a great many places in the United States at the same time, we should find that they would not be the same. The readings would show that in some parts of the country the pressure is high, while in others it is low. We might find, for instance, that the barometers read 29.8 inches in Iowa but

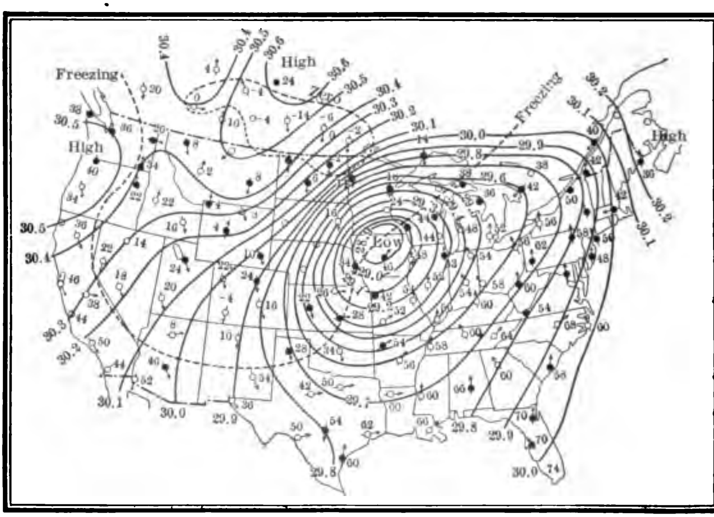

Fig. 25. Weather map for March 14, 1913

only 29.5 inches in Indiana. An examination of the facts will show that the pressure is never the same all over the country and that it does not long remain stationary at any one place.

If the pressure of the air is high in Iowa and relatively low in Indiana, we can see that the air next to the ground in Iowa will tend to flow away toward places of less pressure. It will move from Iowa toward Indiana across the intervening state of Illinois, and Illinois will therefore have a wind

from the west. If the difference of pressure between Iowa and Indiana were only 0.1 inch, the wind would be light; if the difference were as much as 0.5 inch, the wind would be much stronger.

In general it may be said that there are always differences of pressure between various parts of the country and that the air is always flowing from regions of high pressure to regions of low pressure.

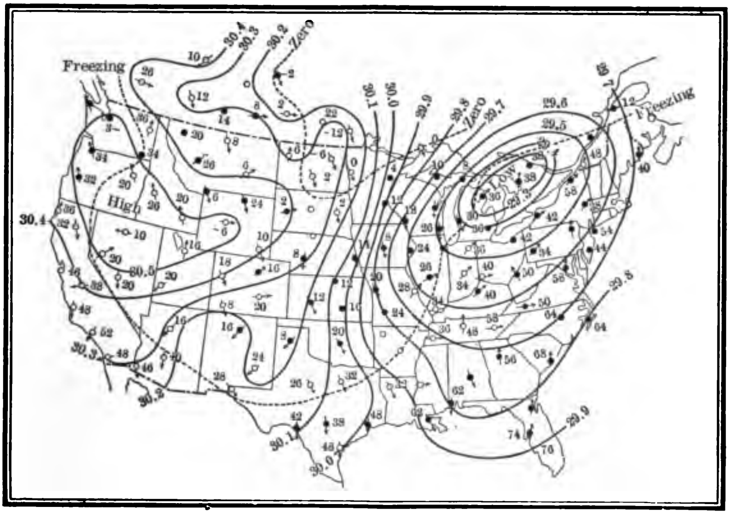

Fig. 26. Weather map for March 15, 1913

40. Pressures as shown by weather maps. A good idea of the distribution of high and low pressures (figs. 24, 25, and 26) throughout the country may be obtained by looking at a weather map. The air pressures are represented on the maps by heavy black lines. These lines are drawn in such a way that all places which have the same air pressure are shown on one line, and the figure which represents this pressure is marked upon the map close to the line. These lines connecting regions of the same air pressure are called *isobars.*

The map is made in the following manner: Each morning at eight o'clock (Washington time), at every weather-bureau station in the United States, the barometer is read and the reading telegraphed to Washington. There the readings are placed upon a map, each at the location of the city from which it was telegraphed. The lines are then drawn through places having the same pressures. These lines thus make it possible to see very easily where the high-pressure and low-pressure centers are located. Usually a map will show several well-defined areas of this kind.

41. Progression of high and low pressures. Observation of maps on successive days will disclose the fact that a "low" moves eastward across the country at the rate of several hundred miles per day, and often several of them may be on the map at once. The centers of the "lows" commonly cross the northern part of the United States and almost invariably pass through the St. Lawrence River valley. The "highs" occupy the spaces between the "lows" and also proceed eastward across the continent, but their course is usually inclined toward the southeast, and their progress is not so regular as that of the "lows." Both "highs" and "lows" are commonly elongated in a north-and-south direction and are often compared to a series of great waves in which the "highs" are the crests and the "lows" the troughs.

42. Winds about a "low"—cyclones. Since a low area usually has a more or less circular form and is surrounded by higher pressures, it follows that the air will tend to move into the low area from all sides. If there were nothing to direct the course of the wind except its tendency to blow toward the lowest pressure, it would blow from all directions straight across the isobars toward the center of low pressure. An examination of the weather maps, in which the wind direction is indicated by arrows, shows that while the wind does blow into the low areas, it does not blow straight toward the center of the "low." Instead of moving as we should

expect, the air turns a little to its right. That is, at a point north of the "low" the air is moving not south but southwesterly; at a point east of the "low" it may be moving northwest instead of west; and so likewise for other places in the vicinity of the "low."

This deviation of the wind from the expected direction is due to the rotation of the earth on its axis. The rotation does not cause the wind to blow, but it does affect its direction. The effect of rotation upon moving bodies may be illustrated by pouring water upon a rotating globe. If a smooth-surfaced globe is placed with the pole which represents the north pole of the earth pointing upward, and rotated while the water is poured upon it, the water marks on the surface of the globe will not run directly from pole to pole, like meridians (fig. 27), but will be curved to right or left. If the globe is rotated in the same direction as the earth is rotating, the paths of the water will curve to the right (westward) in the northern hemisphere, but as soon as the drops cross the equator they begin to curve to the left (eastward). Precisely the same thing occurs on the surface of the earth. It is a general law that anything moving on the surface of the earth will tend to follow a curving path. In the northern hemisphere

FIG. 27. Deflection on a rotating globe

Water was poured upon the top of the globe while it was rotating from left to right. The direction of the water is reversed after crossing the equator

this path curves to the right, and the direction of the rotation of cyclones and other storms is opposite to the direction which is followed by the hands of a clock, or counterclockwise; in the southern hemisphere deflection is to the left and the rotation is clockwise (fig. 28).

There are at least two factors controlling the movement of the wind: the differences of pressure, which cause the air to move across the isobars toward places of lower pressure; and the rotation of the earth, which deflects the moving air to the right of the course which it would otherwise follow. Since the effect of the earth's rotation is the same, regardless of whether the air is moving east, west, north, south, or in some intermediate direction, the air about a "low" will circle about it before reaching the center. Each mass of air will travel in a spiral direction, and the whole body of air about the "low" will rotate. The action of the air is like that of water when it is running through a hole in the bottom of the vessel containing it. We must therefore think of a "low" as a great whirlpool of air sometimes as much as a thousand miles in diameter and moving slowly eastward. Such a great spiral whirl is called a *cyclone*. The cyclone must not be confused with a very destructive storm that sometimes occurs and is often called a cyclone, although the proper name is *tornado*. The air about a "high" will be deflected to the right and thus will circulate spirally outward. This is called an *anticyclone*.

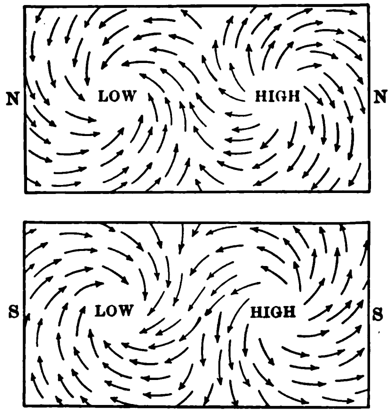

FIG. 28. Deflection of air currents

Diagram of air currents as affected by rotation of the earth. Both northern (N) and southern (S) hemispheres are shown

43. Temperature in a cyclone. When warm winds blow to a cooler part of the country, they cause it to become warmer, as when a south wind blows over the Northern states and produces higher temperature. Likewise a wind from the cold plains of the Northwest in winter may carry a freezing temperature all the way to the Gulf coast. Since the winds come into a cyclone from all directions, it follows that there must be parts of it in which cool air is going southward and cooling warmer places, and other parts of the storm in which warm air from the south is carrying warm weather northward. Let us consider as illustration the case of the warm air from the south and its effects on temperatures in the cyclone. If we refer to the diagrams of cyclones or to the weather maps, we see that the spiral course of the air which comes into the "low" from the south carries it a little to the east of the center of the "low." This means, of course, that the eastern part of the storm will have southerly and warm winds. The western part, on the contrary, will consist of air which is coming from the north or northwest and is comparatively cool. We may therefore expect to find that the temperature rises as a "low" approaches any given region, and falls as it passes. On weather maps places of equal temperature are connected by dotted lines, just as places of equal pressure are connected by continuous lines. The lines representing equal temperature are called *isotherms*.

44. Humidity in a cyclone. We are probably as much concerned about the humidity of the air and about clouds and rain as we are about the wind or temperature. In a previous chapter we learned that the relative humidity varies when the temperature varies. Air which appears moderately dry when it is hot may appear to be very moist when cooled, and some of the moisture may condense. When air from the south is moving northward and warming the country over which it passes, it is itself losing heat and becoming cooler. As it becomes cooler the relative humidity becomes

greater, until finally, at some distance above the earth, saturation may be reached and moisture may be condensed in the form of clouds. If condensation continues, rain will fall. As pointed out before, the warm southern winds are blowing northward in the front part of the storm (the eastern half), and it is here that clouds and rain are found.

In the western half of the storm the winds are coming from northern and cooler places and are being warmed. Capacity for moisture is increasing, and there is no condensation in this part of the storm area. The air in the western part of a cyclone is usually clear, dry, and relatively cool.

Large bodies of water and great irregularities of the earth's surface, such as mountain ranges, may cause marked local variations in the character of the weather which accompanies the passage of cyclones.

45. Passage of a cyclone. On the average, several cyclones pass eastward over the United States each week. Cyclones and anticyclones commonly follow so closely upon one another that we are practically always in one or the other. Most of the winds which we experience are cyclonic winds, and most of the rainfall in the Mississippi Valley is produced by these winds. The events that occur in connection with the passage of a cyclone have been described as follows in a pamphlet issued by the United States Weather Bureau:

When the wind sets in from points between south and southeast, and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or to the north of the observer within twelve to twenty-four hours, with winds shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast, and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within twelve to twenty-four hours, with winds shifting to northwest by way of north. The rapidity of the storm's approach, and its intensity, will be indicated by the rate and amount of the fall in the barometer.

46. Weather in anticyclones. The air which flows into a cyclone usually rises when it reaches the center of the storm, and thus the circulation is kept up. An anticyclone is an area in which the cooler air of the upper regions is settling to the surface and flows away in all directions as described. Since this air at the surface of the earth has come from the cooler regions above, it is getting warmer, and as it flows away from the center of the "high" most of it is still going to warmer regions. Since it is becoming warmer, it is relatively dry. For these reasons the weather in a region covered by a high-pressure area is usually cool, clear, and dry, with a west or northwest wind. Most of us have no difficulty in recalling the bracing air of the pleasant days which follow a period of clouds and rain, and this is typical anticyclone weather.

47. Hot and cold waves. A large low-pressure area sometimes draws so much air from the south into the northern part of the country that the temperature of the north rises unseasonably high, producing a period of very warm weather which is usually called a hot wave, or a *sirocco*. In the western part of the Mississippi Valley the crops are sometimes seriously damaged by hot winds coming off the deserts of the southwestern part of the United States.

If a high-pressure area remains for a while in the Northwest, the cold air which comes from it may spread over the greater part of the country (fig. 29); and if the fall in temperature is rapid and of considerable amount, it is called a cold wave. The presence of low pressure over the Gulf of Mexico or over the Atlantic Ocean near our southern coast will usually assist in the progress of the cold wave. It occasionally happens that the freezing temperatures reach the Gulf coast and even extend far down the Florida peninsula. In these cases there is great loss resulting from the freezing of orange trees and the crops of early vegetables. On the great plains of the West the cold wave may be accompanied by a strong wind and considerable driving snow. In this case it is

called a *blizzard.* It frequently happens that people who are caught in a blizzard are unable to find their way home and are frozen to death. Almost every winter great numbers of cattle and other live stock perish in the blizzards known as *northers.*

48. Hurricanes. Hurricanes are storms of the same general character as the cyclones, but they originate only over the oceans. Those which affect the United States have their

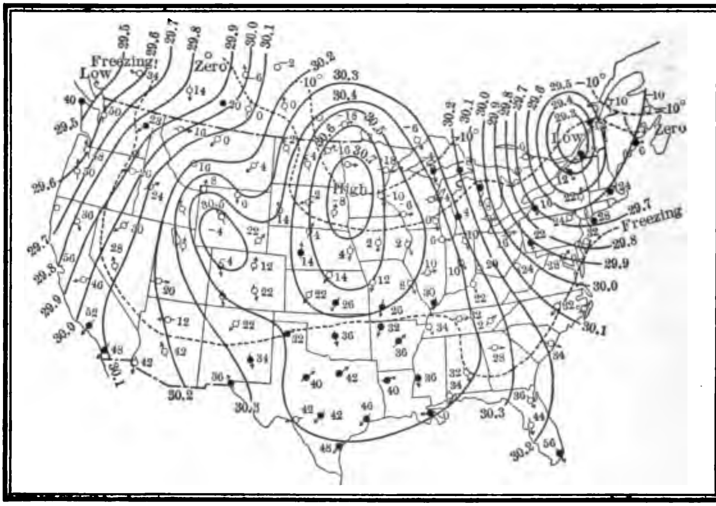

Fig. 29. An unusually large "high" area

Note the low temperatures throughout the country. United States weather map for January 12, 1914

origin near the West Indies. They usually move westward toward the coast of the southern United States and then gradually curve northward and northeastward and pass out across the Atlantic Ocean with decreasing severity. It is very common for them to pass almost parallel to our eastern coast and to do a great deal of damage to shipping. Occasionally one of them goes far enough west to enter the Gulf of Mexico. In the year 1900 the city of Galveston was almost destroyed by a hurricane which had taken this unusual course (fig. 30).

These storms are of very much greater severity than the cyclones and often do a great deal of damage in the West Indies and occasionally upon the mainland.

49. Thunderstorms. In the warmer parts of the year the layers of air next to the surface of the earth may become much warmer than the air higher up, and this difference may become so great that the lower layers are distinctly lighter

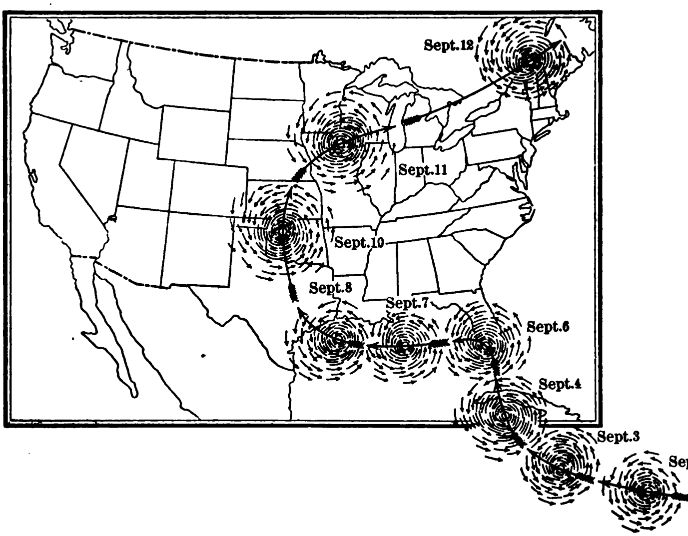

FIG. 30. The path of the Galveston hurricane

Diagrammatic representation of the position of the storm on several successive days. Its intensity was much decreased after it left the Gulf of Mexico. After the United States Weather Bureau

than the upper layers. If this is the case the lower air begins to rise through the upper air in ascending currents somewhat like the ascending currents of air over a heated stove. At a height of several thousand feet the ascending air may be sufficiently cooled to cause the condensation of some of the water and the formation of the dome-shaped white clouds which are such familiar objects in summer skies. These clouds are called *cumulus* clouds.

If the conditions are such as to cause very vigorous movements of the air, and if there is a good deal of water in the lower air, the clouds may grow until they become heavy and dark and rain begins to fall. The fall of rain is accompanied by lightning and thunder, as well as by considerable wind. After the storm has passed, the temperature is cooler because the warm air has flowed away upward and has been replaced by cooler air from above.

FIG. 31. A tornado cloud

Note the "funnel" reaching from the upper clouds to the earth. Mount Morris, Illinois, May 18, 1898

Thunderstorms usually occur in the southerly part of a cyclone during warm weather and in the warmer part of the day, but they may occur even in winter. They move eastward across the country at a rate of from twenty to fifty miles per hour and may affect a region many miles wide or be restricted to a width of a fraction of a mile. They also vary greatly in severity, but are not commonly destructive.

50. Tornadoes. In the United States, particularly in the central part, there are occasional storms of very great severity over a limited area. These storms are called *tornadoes* (sect. 42). Like the thunderstorms, they are due to the excessive heating

of lower air, which is also nearly saturated with water vapor. They differ from the thunderstorms in that the ascending current is very strong and has a rotary motion. The movement of the air in such a storm resembles that of water in a whirlpool (fig. 31).

A tornado commonly occurs within the southeast quarter of a cyclone and moves toward the northeast, the direction of the prevailing wind, at about the same rate as a thunderstorm moves. The condensation of water and the presence of dust and dirt which have been blown up by the whirl make the storm visible as a conical or funnel-shaped cloud which is whirling rapidly.

The path of a tornado is never wide and may not be more than 100 or 200 feet in width. Within this path the destruction is often so complete that all buildings, fences, trees, etc. are leveled to the earth or carried long distances.

The velocity of the wind within the central whirl is very great, but it has not been possible to measure it. From the character of the results which are produced, it is estimated that the wind velocity may be as high as five hundred miles per hour. The storm at Mount Morris, Illinois, in 1898, and the one which passed from the vicinity of St. Louis, Missouri, across Illinois and Indiana in 1917, of which pictures are shown, carried off heavy objects, such as stoves and pianos, destroyed buildings to the foundation (fig. 32), drove light sticks and straws through or into boards and posts, plucked the feathers from living chickens, and did many other peculiar things.

Fortunately such storms cover such a small area and occur so rarely that the chance of any one place being visited by one of them is not great. Tornadoes sometimes occur at sea and are then known as waterspouts.

51. General circulation of air on the earth. The surface of the earth may be divided into zones, or belts, characterized by different sorts of winds. The belt which we have been discussing is called the belt of westerly winds, because the

FIG. 32. Results of a tornado

Trees and buildings demolished by the tornado of May 26, 1917. This tornado began in Missouri, crossed Illinois, and almost crossed Indiana, leaving a path of destruction as evidence of the power of rapidly moving air

lower winds are from a westerly direction more frequently than from any other. It is true also that the upper air currents in this region are from the west, as is shown by the movement of the higher clouds. This is always from the west.

The winds of this belt are so much disturbed by the passage of the cyclones that it is difficult to see any regular eastward movement until one recalls that the cyclones themselves move eastward. This eastward movement is doubtless due to the fact that they are merely great whirls in the greater mass of eastward-moving air. It will also be recalled that thunderstorms and tornadoes move eastward, as, indeed, is true of practically all weather conditions. It is in the western sky that we usually see the first indication of the coming storm; the first lightning flashes are usually seen in the west; and it is in the west that the clearing of the sky begins after the storm.

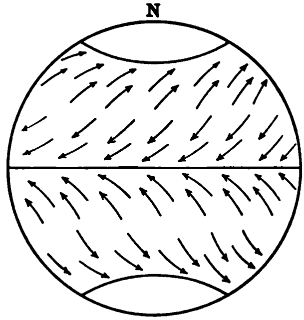

Fig. 33. Diagram of the general circulation of air upon the earth

These general currents are always more or less modified by local conditions

This belt of westerly winds, with its cyclones and other phenomena, extends entirely around the earth in this latitude (fig. 33). Mountain ranges which cross the path of the westerly winds have much heavier rainfall on the western than on the eastern side, because the winds, as they ascend the western side, are cooled and some of the moisture condenses into clouds and rain, while on the eastern side the air is warming as it descends and becomes relatively dry. A good example of this will be found by comparing the rainfall on the west slope of the Cascade Mountains in Washington and Oregon with the rainfall on the east side of the same mountains (fig. 34).

In the tropical regions we have the belt of trade winds on each side of the equator. The great heat of the equatorial regions causes the air to expand and thus become less dense, and it is pushed upward in the region of greatest heat, — the heat equator, which is near the true equator. In this

region of rising air there is little wind at the surface of the earth, and it is known as the belt of calms. To the north and south of the belt of calms the air is rushing southward (or northward) toward the heat equator, but by the rotation of the earth these winds are turned from the direct course they would otherwise pursue, so that in the northern hemisphere they become northeast winds and in the southern hemisphere they blow from the southeast. These winds blow very steadily, and are known as trade winds.

52. Rainfall in the United States. Rainfall is very unequally distributed in the United States (fig. 34). It ranges in amount from 100 inches per year in northwestern Washington to 2 inches per year in southeastern California. While there are no very large regions in the United States which deserve to be called deserts, yet much more than a third of the country is arid and cannot be farmed successfully without irrigation or other special means. The eastern slope, the lake region, and the Mississippi Valley as far west as the middle of the Dakotas and Nebraska are well watered, but the great plains and mountains of the West have very scanty rainfall excepting on the westward slopes of mountains near the Pacific Ocean.

The rainfall on the Pacific coast is due mainly to the effect of the mountains upon the prevailing westerly winds. The scantiness of rainfall in the mountains and on the plains directly east of them is due to the same thing. The larger rainfall of the Mississippi Valley occurs principally in connection with the cyclones and is condensed from the air which is sweeping northward from the Gulf of Mexico into the cyclones. Farther east the Atlantic Ocean contributes in the same way.

53. The United States Weather Bureau. The importance of the weather to the people of the country is so great that the government has established a bureau for the purpose of studying the weather and forecasting it as far as possible.

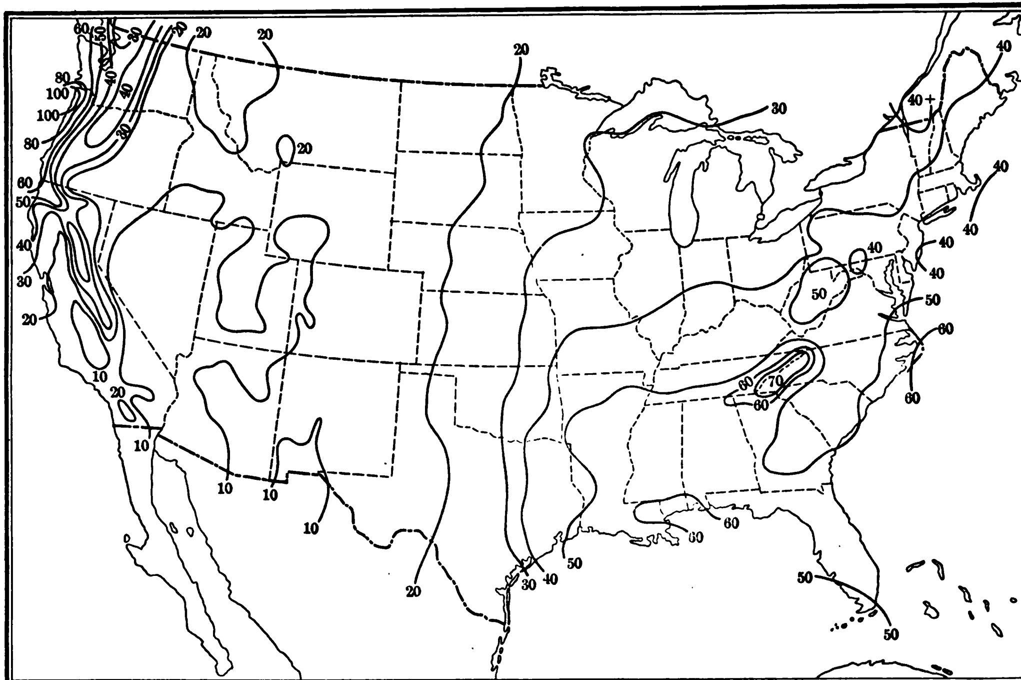

Fig. 34. Normal annual precipitation in the United States

The lines pass through points which have equal precipitation. The figures are for depth of water in inches. From the United States Weather Bureau

While it is not possible to foretell the weather with certainty, the predictions that are made are fairly accurate and have been of great value.

All forecasting of weather is based upon the weather map. The map is made up each day from the reports telegraphed from the observation stations all over the country. The predictions are based almost wholly on knowledge of the character and actions of cyclones. The usual path of cyclones and the rate of motion have been carefully studied, and it is possible to estimate quite closely what a cyclone will do within the next twenty-four hours, and therefore how weather conditions will change. For instance, if it were found that within twenty-four hours a cyclone that is now in the West could be expected to approach to within a short distance of a certain place, it would be safe to predict clouds and rain for that place. On the other hand, the approach of a high-pressure area would justify the prediction of clear weather.

The difficulties in forecasting are many, and most of them arise from the irregularities in the behavior of cyclones. If all cyclones moved in the same path at the same rate and did not change in violence, we should be able to predict the weather with almost absolute certainty. But cyclones sometimes travel in unexpected directions or at unusual rates. Sometimes they disappear entirely, and sometimes new ones make their appearance without any warning. In spite of all these difficulties the art of forecasting the weather has been brought to a high degree of reliability.

The storm warnings at ports on the ocean and Great Lakes are the means of saving annually many lives and hundreds of thousands of dollars' worth of property. The warnings of frosts have saved in a single year as much as $3,000,000 worth of perishable property in the form of fruits and vegetables. Flood warnings are another important part of the work of the bureau.

CHAPTER V

STRUCTURE OF THE AIR — MOLECULAR THEORY

54. Questions for Discussion. **1.** When an automobile or bicycle tire has been pumped up, is there more air in the tire than before pumping? **2.** Bicycle and automobile tires which have been filled in the early morning sometimes burst, or blow out, near midday or in early afternoon, although they are not punctured. Why? **3.** What becomes of milk or sugar when it is thoroughly stirred in coffee or tea? **4.** Could you take the milk or sugar out of the coffee or tea after it was thoroughly stirred into it? **5.** Why is it that if a small amount of musk or other strong perfume is released in a closed room, the perfume may soon be detected in any part of the room, possibly in adjacent rooms? **6.** Do you know of any substances which can be changed from solid to liquid and from liquid to gas, or changed in the opposite direction? Is the substance destroyed during any of these changes? **7.** What happens to a solid, such as ice, when it is changed into a liquid? when it is changed into a gas? **8.** If a room is full of air, how is it possible for another gas which is released in the room also to fill the room? **9.** When a tumbler full of water has a drop of red ink placed in it, how can the ink become distributed throughout the water? **10.** What is the nature of the structure of gases which makes it possible for one gas to pass throughout a room which is already occupied by another gas?

55. Compressibility of air. In Chapter I we learned that air pressures vary and that they may be measured. If a pneumatic tire is filled with air so that it is fully expanded and also feels quite firm, we say that it is "filled" with air. If it were filled with water in like manner we should not expect to be able to get any more water into it, but we know very well that if we apply the pump we can force in more air. As we continue to pump, the tire gets firmer and the pump works harder, showing that there is greater

pressure in the tire. There seems scarcely any limit to the amount of air that can be forced in, so long as our strength endures and the tire does not burst. How can this additional amount of air get into the tire? Plainly the air that was in there before must have been forced to occupy less space than before, or else the old and the new have mingled within the space formerly occupied by the old. In either case they both together occupy less space than they would if they had not been forced into the tire. In other words, the air has been compressed.

Instead of pumping air into the tire, we might have squeezed the tire together. We should then have forced the tire and the air that it contains to occupy less space than they did before, again showing that it is possible to compress air into smaller space.

56. Expansion of gases. In experiments such as we have mentioned we notice that a gas resists a compressing force. It does not surprise us, therefore, that when the gas is released it expands again. When a tennis ball filled with air is compressed and then released, it illustrates this point.

Suppose, furthermore, we attach an air pump to a bottle and exhaust the air from it. When we have pumped half of the air out of the bottle, is one half of the bottle filled and the other half empty? By no means. The air is just as plentiful in one end of the bottle as in the other. Indeed, no matter how much air we may remove, if there is any left in the bottle it expands so as to fill the whole bottle.

In the same way, if we inclose some air in a rubber bag and pull the sides of the bag outward so as to make more space inside of it, the bag will still be filled with air. No matter how much the bag is enlarged, the air will continue to expand and fill it.

Air and other gases seem to possess the power of indefinite expansion. A gas always expands so as to occupy the whole space that is open to it.

57. Diffusion of gases. If there is a leaking gas pipe in a closed room, the odor of gas can soon be noticed in any part of the room. The fact that the odor can be found in all parts of the room indicates that the gas has spread to the most remote corners. How did it get there? If there were currents of air, it might be carried by the currents, but the same result is observed even if the air is quiet. It seems, therefore, that the small amount of gas that has been released from the pipe in one part of the room has somehow managed to distribute itself more or less evenly through the whole room without being much affected by the presence of the air. In other words, although the room was occupied by the gas which we know as the air, the gas which escaped from the pipe has spread itself through the room as if it were the only gas present.

If other gases are used, the same results follow; and careful tests show that when several gases are in a space at the same time, each one of them soon becomes evenly distributed throughout the space. This property that gases have of mingling with one another when in contact, even if not stirred, is called *diffusion*. The same property is shown in liquids also.

From these experiments it might appear that two or more substances (gases in this case) can occupy the same space at the same time. Do you think that this is really true? Is it true of solids? of liquids?

58. Some questions regarding gases. How can one substance pass through another substance, as when illuminating gas diffuses through the air from one part of the space to another part? Certainly two persons or two books cannot occupy the same space at the same time. Furthermore, how may a substance be made to occupy less space, as it does when air is compressed? When a sponge, which is porous, is compressed, the pores are made smaller, but it is the pores which are really compressed, and not the substance of the

sponge. Such a substance as iron does not appear to be porous, and we do not find it easy to compress it into smaller space. If air is porous, that may also explain how the illuminating gas passed through the air and how it is possible for air and other gases to expand and contract.

59. A theory about the air. In the attempt to answer the questions that we have been asking about the air and also to explain many other matters, scientists have formed a theory which seems to account for a great many facts in nature. This theory is that the air is not a perfectly continuous substance, but that it is formed of a great many particles, each a little distance from the other particles. These particles, called *molecules*, are believed to be extremely small. It is believed that they are in rapid motion and that one molecule moves in a straight line until it strikes another, when it rebounds and again moves in a straight line. It is supposed that molecules are continually moving and striking one another at very short intervals. This theory of the structure of the air and of other substances is called the molecular theory. As the question is more thoroughly investigated more evidences are found that agree with the theory, and as yet nothing has been found that is opposed to it. All scientific men have come to accept it as a reasonable explanation and one that is probably true.

60. Molecular theory applied to air. In the case of the diffusion of illuminating gas through the air of the room, the molecules of the gas simply pass through the spaces between the molecules of air. According to this explanation gases are compressible because they are porous. Perhaps it may illustrate the condition of a gas if we imagine both the molecules and the spaces to be greatly magnified. If the molecules were to be magnified to the size of baseballs, they would have to be about two feet apart to preserve the proportion; that is, a gas consists of material particles with spaces between them, and when the gas is compressed, the

particles are forced together. The force with which air or any other gas resists compression makes it appear that in some way the particles resist being pressed together and are ready to fly apart again, as they do, in fact, when the pressure is removed and the gas expands.

61. Gas pressures. If you strike a blow upon a punching bag, it is pushed to one side and immediately returns, but if you hit it again as it starts to return, and continue to strike one blow after another very rapidly, the bag will remain pushed to one side as long as you continue to strike. The molecules are believed to be doing something very similar to this. They not only strike against each other but if the gas is inclosed they also strike against the walls of the containing vessel. Since they are so small, each blow is very insignificant indeed, but there are so many of them that they strike innumerable blows every second upon each square inch of the containing surface and the sum of these blows is very great. The result of all these blows is that the gas exerts pressure against the walls which confine it, for instance, against the inside of the rubber tire.

62. Heat, molecular movement, and gas mixtures. As the temperature of a gas increases, the speed with which its molecules move increases. Since they move faster, they strike harder when they hit the walls of the tire or other container, and the pressure is greater. This agrees with our observation, for we find that pressure exerted by a confined gas always increases with the temperature.

According to this theory, when two or more gases are mixed, their molecules are intermingled, but each kind of molecule remains unchanged. If some means of sorting the two kinds of molecules is available, the two gases may be recovered unchanged. A gas like the air may be made up of a mixture of molecules of several different kinds of gases, just as a swarm of gnats may be made up of several kinds of gnats.

63. Liquids and solids. It may be more difficult to believe that liquids and solids are composed of molecules, but this is thought to be the case. It is not very difficult if we recall the fact that gases can be condensed into liquids — for instance, when steam becomes liquid water, or in the formation of liquid air. Likewise, liquids may be frozen into solid form. It follows, then, that solids and liquids, like gases, are made of molecules.

There are some differences, however. The molecules of a liquid seem to move about readily — almost as readily as they do in a gas, but they do not have the same tendency to fly apart. Thus the liquid changes form, but it remains the same in volume. It does not readily expand and is not easily compressed. The solid also is not easily compressible, since its molecules do not readily shift their positions. It has a permanent shape. The spaces between the molecules in a liquid or a solid are much smaller than in a gas, but there must be some space, else we could not dissolve substances in water. Even so compact a substance as gold will absorb certain other substances, and we believe that the molecules of the dissolved substance find their way into the spaces between the molecules of gold.

If alcohol, which is lighter than water, is carefully poured into a test tube half filled with water, at first most of the alcohol will float upon the water, but after some time it will be found that the two liquids have become evenly mixed. In a similar manner a lump of salt or sugar dropped into a vessel of water will dissolve and diffuse throughout the water. Diffusion occurs in liquids as it does in gases.

CHAPTER VI

COMPOSITION OF THE AIR—ATOMIC THEORY

64. Questions for Discussion. **1.** Will a lamp burn if the top of the chimney is closed? **2.** Why are there holes in the base of the burner of a lamp or lantern? **3.** How does the kerosene or candle oil reach the flame? **4.** Is there a nonluminous portion in the flame of a kerosene lamp? in a gas flame? **5.** What should be done to correct a smoking lamp chimney? **6.** Why does a person hold his hand around a match when he first lights it? Is similar protection needed when starting a wood or coal fire? in starting a gas fire? **7.** Why is the flame of a lamp or candle driven upward? **8.** Why is it dangerous to pour gasoline in a room where there is a flame? **9.** How do you explain the presence of water on the inside of a lamp chimney immediately after lighting the lamp? Why does this water later disappear? **10.** Would kerosene or gas flames used for lighting affect the need for ventilation in a room? **11.** Why does carbon dioxide sometimes remain in wells or cisterns when most gases would escape? Why do workmen lower a lighted lantern into an old well before they descend into it? **12.** Why is carbon dioxide valuable for use in fire extinguishers? **13.** It is said that the first thing to do in case a person's clothes catch fire is to cover the person with a blanket or robe. Why? **14.** Why do iron fences rust? How may we prevent objects from rusting?

65. The air not a simple substance. When you consider what we have learned about the air in connection with preceding chapters, you may recall several facts which have shown that the air is not composed of one substance only. For instance, we found that water vapor is often a very considerable part of the air. The air is in fact a mixture of several gases, of which water vapor is one. We should get some acquaintance with at least the more important of these and learn how they act. As a means of securing such

acquaintance, we shall study the flame of a candle in its relation to the air.

If a candle is thrust into a lamp chimney which is held in an upright position, the flame will burn more brightly and steadily than in the open air; but if the lower end of the chimney is closed by the hand, the flame becomes smoky, flickers, and possibly is extinguished. In the first case the heat of the flame warmed and expanded the air in the chimney, thus causing an upward current of air (Chapter I), so that the flame was better supplied with fresh air than when it was in the open. When the hand was placed across the bottom of the chimney, however, the upward current of air was interrupted and the supply to the flame was so much reduced that burning was no longer possible.

FIG. 35. The candle flame

Note the general form of the flame, the light outer part, and the dark center

66. A burning candle. When a candle is lighted, the flame burns at the top of the wick but does not come down the wick to the solid part of the candle (fig. 35). The heat soon forms a cup in the top of the candle by melting the center of it. This cup is filled with melted tallow or wax. The melted wax is absorbed by the wick and travels upward in it, just as ink is absorbed by blotting paper and spreads through it. As the melted wax goes up the wick and gets closer to the flame, it gradually becomes hotter and finally begins to burn. The point at which it gets hot enough to burn is marked by the bottom of the flame.

The melted wax or oil really gets so hot before it burns that it changes from a liquid into a gas and burns as it is passing away from the wick. By looking closely at a flame

one may observe that the burning is not taking place immediately at the surface of the wick, but occurs chiefly in the outer part of the flame.

That there is a gas in the flame may be easily proved. Place a small tube so that the end shall be in the center of the flame, and try to light the other end (fig. 36). If this is properly done we shall have a small gas flame burning at the end of the tube, some distance from the candle flame. If the end of the tube is not placed in the center of the flame, but at the surface, the gas secured cannot be burned, because the gas is burning at the surface of the flame. If a large piece of paper is held across the widest part of the flame, the paper directly above the center of the flame will not at first be burned. The part of the paper which is first burned forms a ring corresponding to the position of the outer part of the flame. The same tests may be carried out with the flame of illuminating gas in a Bunsen burner.

Fig. 36. Inflammable gas secured from the flame

By the use of a tube the unburned gas from the center of the flame may be conducted outside and there burned

67. Products of the flame. When the gas formed from the wax of the candle has been burned, it has not passed out of existence, although it has changed so that we may not at first be able to recognize it. These changes are not merely in temperature and expansion, which we have been discussing in former chapters, for if this were true, the gas which passes away from the flame would condense into a liquid, and the liquid would harden into the kind of wax with which we started. The molecules which leave the flame and mingle with the air are different from the molecules of the wax as they come to the flame.

68. Water produced by a flame. If a cold object, such as a piece of iron or a test tube full of water, is held in the flame, soot may collect on it. We shall not give attention to the soot for the present. Another thing that we shall find in the flame is not ordinarily expected. Drops of water collect upon the cold object; but if the object is allowed to get hot, the water evaporates again. The water came from the flame and was formed in the flame. Furthermore, if a gas flame is used instead of a candle flame, and every precaution is taken to make sure that there is no water vapor either in the gas or in the air, the same result follows. Since this water was produced from substances other than water, it is important for us to know what changes and what substances have produced it. The best way to find what substances compose water is to find what results when water is decomposed. It is not easy to determine what the component parts are, and we shall have to use experiments directly related to that problem. These experiments require the use of an electric current, which we shall study later, but at this time we shall give our attention to the composition of water.

69. Composition of water. When we put the ends of two platinum wires in water and pass a current of electricity through the water between the wires, it is noticed that bubbles of gas arise from both wires. By suitable apparatus it is possible to collect these bubbles until there is enough gas to allow us to examine it (fig. 37). It will be noticed that the volume of gas that may be collected from one wire is about double that collected from the other. Both gases are colorless and look like air. One of them, that of the greater volume, takes fire and burns with a pale blue flame; the other does not take fire, but a splinter burns much more brilliantly in it than in the air. The one which takes fire is called *hydrogen*; the one which makes other things burn more brilliantly is *oxygen*. They can be caused to unite, and when they do so they form water. We may conclude that

water is made up of two substances, hydrogen and oxygen, and that the electric current causes them to separate.

It appears strange that water, a liquid, should be composed of two gases, but such is the case. Are the two gases merely mixed? If so, we should expect to find that the results of the mixture would be a gas, and if we mix hydrogen and oxygen, as we did air and illuminating gas, we have a mixture of gases, nothing more. Water is something different from a mixture. In fact, if we mix hydrogen and oxygen and bring a flame to them, the mixture will explode. After the explosion we cannot find either of the gases, but instead we have water or water vapor. Making a mixture is quite a different thing from forming a new substance. If we mix hydrogen and oxygen we have in the mixture two kinds of molecules — the molecules of hydrogen and the molecules of oxygen. When water is formed we have molecules of only one kind — the molecules of water. The hydrogen and oxygen combine to form the water molecules.

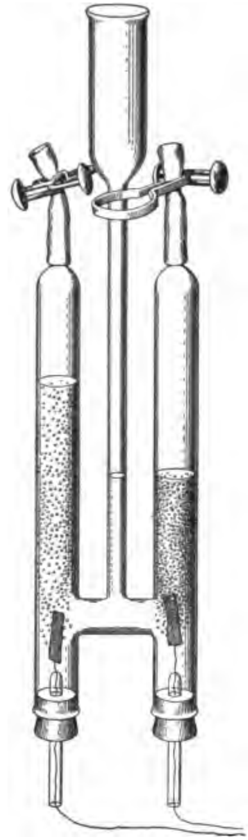

FIG. 37. Decomposition of water

By use of an electric current passed through the water in the tubes the water is decomposed into the hydrogen and oxygen of which it is composed. The upper clear region in the right-hand tube contains hydrogen, and the upper part of the left-hand tube contains oxygen. The volume of hydrogen is twice that of the oxygen

70. The molecule of water. The theory held by scientific men is that the molecule of water is not a simple thing — that it is composed of two kinds of particles. These particles are called *atoms*. The atomic theory states that each molecule is commonly made

up of two or more atoms and that these atoms may be of the same kind or of different kinds.

Each molecule of water is believed to contain both hydrogen and oxygen atoms. When we decomposed water by the electric current, we secured twice as much hydrogen as oxygen. That would suggest that in the molecule there is twice as much hydrogen as oxygen. Further study by chemists has shown that in a molecule of water there are two hydrogen atoms and one oxygen atom.

Chemists let a certain letter stand for a certain kind of atom. Thus, H stands for a hydrogen atom and O for an atom of oxygen. If there is more than one atom, a small figure is written below and to the right of the letter to tell how many atoms are meant. Written in this way the symbol for a molecule of water is H_2O.

71. Explanation of some chemical terms. When a substance is made up of molecules having two or more kinds of atoms in them, as in water, it is clear that it is possible to separate such a substance into two or more different substances, as we did with water. Such a substance is called a *compound substance.* Water is a compound. A substance whose molecules have in them only one kind of atom, as oxygen, cannot be separated into simpler substances. It is called a *simple substance* (element). Hydrogen, oxygen, iron, silver, lead, copper, and gold are examples of simple substances.

When a compound is separated into its elements or into simpler compounds, the process is called *chemical decomposition.* Have you seen an example of chemical decomposition? It is sometimes said in that case that the compound has "broken down." Any change in a substance in which the molecule is changed by atoms being taken away from it, added to it, or exchanged for others is called a *chemical change.* So long as the molecules remain the same, there is no chemical change.

The following table contains the names of the more important simple substances, their symbols, and a few words

descriptive of their appearance and condition at ordinary temperatures. Those marked with a star are metals. Look over the table and note what familiar substances are simple substances or elements. There are in all not less than eighty-four known simple substances, and claims have been made of the discovery of several others.

Name	Symbol	Description
*Aluminium	Al	A white or silvery solid, very light in weight.
Antimony	Sb	A bluish-white solid.
Arsenic	As	A gray solid; it and its compounds are poisonous.
*Barium	Ba	A solid.
Bismuth	Bi	A solid.
Boron	B	A solid.
Bromine	Br	A dark-red liquid, much heavier than water.
*Calcium	Ca	A solid.
Carbon	C	Commonly a black solid, but when crystallized it may be transparent; diamonds are crystallized carbon.
Chlorine	Cl	A pale greenish gas with a suffocating odor.
*Chromium	Cr	A solid.
*Cobalt	Co	A solid.
*Copper	Cu	A red solid.
Fluorine	Fl	A very pale yellow gas.
*Gold	Au	A heavy yellow solid.
Hydrogen	H	A transparent, colorless, odorless gas.
Iodine	I	A shining, purplish-black solid, readily changed by heat into a violet gas.
*Iron	Fe	A silver-gray solid, readily tarnished.
*Lead	Pb	A soft, heavy, silvery solid.
*Magnesium	Mg	A silvery solid.
Manganese	Mn	A solid.
*Mercury	Hg	A silvery-white liquid, very heavy.
*Nickel	Ni	A solid; white, hard, not readily tarnished.
Nitrogen	N	A colorless, odorless gas.
Oxygen	O	A colorless, odorless gas.
Phosphorus	P	A waxy solid, spontaneously combustible in air.
*Platinum	Pt	A silvery solid, very heavy.
*Potassium	K	A solid, but easily cut with a knife.
Silicon	Si	A solid.
*Silver	Ag	A white solid.
*Sodium	Na	A solid, but soft enough to be easily cut.
Sulphur	S	A yellow solid, forming many strong-smelling compounds.
*Tin	Sn	A white, moderately hard solid.
*Zinc	Zn	A bluish-white solid.

72. Formation of water in the flame. We now have come back to the question: How was the water formed in the flame? After what we have learned we should expect to find that the water had been formed in the flame by some sort of chemical change. Hydrogen and oxygen unite to form water. The flame is merely a place where chemical changes are occurring.

The wax is a compound containing hydrogen; the air is a mixture containing oxygen and several other gases. When the wax is melted and then turned into a gas by the heat of the flame, this gas mixes with the air, and the atoms of hydrogen leave the other atoms and unite with the atoms of oxygen which are in the air. The compound thus formed is water. When hydrogen and oxygen unite, the union produces great heat, and at the resulting high temperature the water remains in a state of water vapor. It is only when this water vapor is cooled, as by contact with a cold object, that it changes into the liquid form and becomes visible as drops of water.

The flame of the candle consists principally of gases heated to a high degree by the changes which are taking place in the flame. The gases in the candle flame with which we are already somewhat familiar are the vaporized wax, water vapor, and the gases of the air. A flame is always composed essentially of burning gases, but these gases may not always be of the sort that we have found in the candle flame.

73. Other products from the flame. It was said that the candle wax is a compound, and that the hydrogen which unites with the oxygen is taken away from the wax. The wax is a compound containing a great deal of hydrogen and carbon. When the hydrogen is taken away from this compound — that is, when the compound is decomposed — the carbon atoms are left. The small particles of carbon float upward in the flame and are heated red-hot or white-hot. The part of the flame in which the white-hot carbon is present is the part from which the light comes.

The substance which we call carbon is so familiar to us as electric-light carbons, charcoal, lampblack, soot, etc. that it is not necessary to describe it. If a cold object is held in the flame of a candle for a moment, carbon (soot) is deposited upon it.

Some of the carbon may be seen to pass upward from the tip of the flame as smoke, but if the candle is well trimmed, there should be little or no smoke. Carbon as well as hydrogen is able to unite with oxygen, and though there is much carbon in the flame, very little of it passes away from the flame in the form of soot. It unites with the oxygen of the air to form a compound made up of carbon and oxygen known as carbon dioxide.

74. Carbon dioxide formed by the flame. If a candle or other flame is allowed to burn for a time in a bottle of air, and if limewater is then poured into the bottle and shaken slightly, the limewater will become milky. If we do the same with a bottle of air in which the flame has not burned, the limewater remains clear. This shows that there is something in the bottle that was not there before the flame was put into it. Chemists tell us that the substance which caused the limewater to become milky is a gas composed of carbon and oxygen. Is it an element or a compound? We may burn some charcoal (carbon) in a jar filled with pure oxygen. In that case anything that is formed can contain only carbon and oxygen, since there is nothing else in the jar. If we test the results of this burning, as before, the limewater turns white, showing us the evidence of the same substance. This substance which is produced by the burning candle is a compound of carbon and oxygen and is formed by the union of the oxygen of the air and the white-hot carbon particles in the flame.

The proper abbreviated symbol or formula by which to represent a molecule of this carbon-dioxide gas is CO_2. What does this formula mean?

75. Some further facts about carbon dioxide. Carbon-dioxide gas may be made in many ways besides burning. The most convenient, perhaps, is the method of producing it by putting hydrochloric acid on marble (fig. 38). However produced, it is always the same. If we collect it in a bottle, it is found that the gas is perfectly clear and colorless. It will not burn, but instead it extinguishes fire. It may seem strange that things will not burn in carbon dioxide when the gas is composed partly of oxygen, but it must be remembered that the oxygen atoms are joined to the carbon atoms and therefore are not free to unite with something else. Since the oxygen atoms will not leave the carbon atoms of the carbon dioxide, there is no free oxygen to maintain the burning of a flame, and therefore the flame is extinguished.

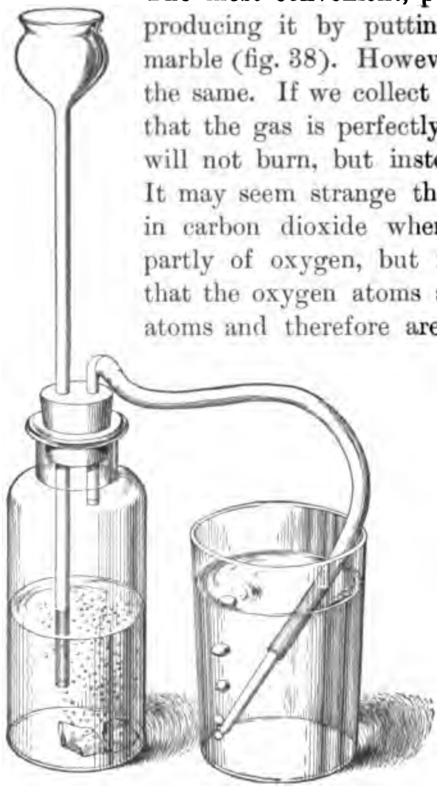

FIG. 38. A carbon-dioxide generator

The bottle contains pieces of marble and hydrochloric acid. The action of the acid on the marble decomposes it, releasing carbon dioxide, which escapes through the bent tube. Additional acid may be added through the funnel

Carbon dioxide is about one and one-half times as heavy as air and therefore can be collected in an open bottle. With care it may be poured from one bottle to another.

It is familiar to us as the gas that bubbles up in our soda water and in other effervescent drinks and as the important substance in chemical fire extinguishers. We make use of it in cooking to raise cake and biscuit.

Sometimes it occurs in wells, cisterns, sewers, and in mines, where it is called choke damp. One may drown in it as truly as in water, since it fills the lungs but does not supply any free oxygen for respiration. There is a very small amount always present in the air, and this will be discussed later.

76. Gases of the air. We have already found that the air consists of several gases. These are merely mixed; they do not form a compound. The most striking one of those that we have been studying is oxygen. It constitutes about one fifth of the volume of the air. Of carbon dioxide there are only about 3 parts in 10,000.

There is yet another gas present in large quantities in the air. It is called nitrogen. We shall have more to say about it in connection with the food of plants and animals. Several other gases have lately been discovered. Dust particles also are always present, and some of these are of great importance.

Below is a table showing the gases which, in addition to water vapor, are commonly found in the air, and the average amount of each, given in percentage. The exact percentage cannot be given because the amounts vary slightly from time to time.

COMPOSITION OF AIR

(Approximately)

Nitrogen	78 per cent
Oxygen	21 per cent
Argon	1 per cent
Carbon dioxide	$\frac{3}{100}$ of 1 per cent

77. Abundance of oxygen. Oxygen is the most abundant simple substance upon the earth. In an uncombined state it makes up about one fifth of the air, as noted above. It is found in combination with almost every known simple substance, forming eight ninths (by weight) of water and about one half of the rocks of the earth's crust. It is estimated that about 50 per cent of the earth is oxygen, and its importance in our lives could scarcely be overestimated.

78. Nitrogen and argon. While oxygen is a very active substance chemically, readily entering into combination with a great variety of other substances, quite the opposite is true of nitrogen and argon. These gases serve to dilute the oxygen of the air, but they remain unchanged under most circumstances. Certain compounds of nitrogen are of great importance, however; the living substance of plants and animals contains nitrogen compounds, and these compounds are essential constituents of the food of all living things.

CHAPTER VII

RELATION OF AIR TO FOOD MANUFACTURE

79. Questions for Discussion. **1.** When bread is burned in baking there has usually been no flame, and the bread has not been consumed as would be true if it were burned in a furnace. What has really happened to the food? What is the black substance produced, and what is its origin? **2.** What plants are the principal source of commercial starch? **3.** What plants are the principal source of commercial sugar? In what countries is most of the world's sugar produced? **4.** How do you account for the yellowish color of a growing wheat field after several cloudy days? **5.** Why do most plants grow slowly in the shade? **6.** Why do leaves of most land plants die if submerged in water? Can you suggest any way in which dust, for example from roadways or cement works, might injure leaves? **7.** What change do green plants produce in the earth's atmosphere? If there were no green plants, would the air probably remain suitable for man's use? **8.** Trace back to its origin the energy which is used to propel a locomotive. **9.** Are carnivorous animals in any way dependent upon plants? **10.** If we were to fill our sleeping rooms with growing plants, would they contribute to the oxygen supply of the air at night? **11.** What plants do you know that grow without contact with the soil? **12.** What makes the stalks of celery white? **13.** If plants are the source of all foods, how do they secure their own food?

80. Sources of our food. A large part of our food consists of plants or parts of plants (such as fruits and vegetables) that are eaten in almost or quite the natural condition. Such substances as flour and sugar are manufactured from plants. Of course in all these cases there can be no doubt that our food comes directly from plants. Another important class of food materials includes meats and other animal products. The animals feed upon plants, and thus there are only one or two stages before we come back to plants as the source of our

food. The more we think of this, the more fully we shall be convinced that almost all the things that we eat come directly or indirectly from plants. The next question is, How do plants produce these food materials?

81. Source of plant food. We hear so much about the importance of good soil that it is easy to make the mistake of thinking that plants secure all their food from the ground. As a matter of fact, although plants are dependent on the soil for a large part of their water and also for foods which furnish them with nitrogen, phosphorus, potassium, and other necessary substances, the gain in weight which they make during growth is far from being accounted for by the loss of weight of the soil. A large part of the material must be supplied from some other source.

Another thing that leads to the same conclusion is that some of the most important substances in plants, as carbon, are not found in the soil or are very scarce there. Wood contains a great deal of carbon, though we do not usually recognize it as such, because there are other substances combined with it. If the wood is heated sufficiently to burn or drive off other substances, that which remains will be a black mass called charcoal. Although the soil and the water contain at times a small amount of carbon, it has been shown that this is not the source of the plant's carbon supply. There is only one other source for the carbon, and that is the air, for the air does contain some carbon in the form of carbon dioxide. It is from this that the carbon of plants is secured.

82. Food of plants. The food materials of plants are not very different from those of animals. For instance, starch and sugar are very common in our own food, and they are also an important part of the food of our common plants. The difference between the food habits of common plants and those of animals is not so much in the sort of things that they require as in the way in which they secure these things. The animal secures the starch, sugar, and other compounds

from a plant or from some other source where they may be found in such a condition that it can use them directly. The plant, on the other hand, is able to make these compounds from very simple substances.

Such compounds as starch and sugar are composed of three simple substances,—carbon, hydrogen, and oxygen. We can easily prove that this is the composition of starch by heating some in a test tube (fig. 39). The heat decomposes the starch, and we have carbon and water. Water, we already know, is composed of hydrogen and oxygen, and therefore we have here the three substances.

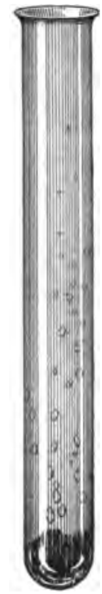

FIG. 39. Decomposition of starch

When starch is decomposed by heat, a black deposit of carbon remains in the bottom of the tube, and water condenses on the inside of the tube

83. The place where food is made. If a green leaf is examined early in the morning, little or no sugar or starch will be found in it. After several hours' exposure to sunshine, however, sugar and starch will be abundant in the leaf, and the quantity will increase with longer exposure to the sun's rays. Sugar is made in the leaf from carbon dioxide and water and converted into starch for storage. Under the influence of sunshine this manufacture may go on in any green part of the plant. Since the leaves are the principal green parts of plants, it is in the leaves that most of the sugar-making is carried on. Sugar may be used as food by the leaf or stored in the leaf after conversion into starch, or may be transferred to other parts of the plant and then used or stored as starch until it is needed by the plant.

84. Some problems. We shall now want to know how the carbon dioxide gets into the leaf, how the water gets there, what chemical changes take place, and what the light does in this process. We shall have to learn certain things about the

structure of the leaf, and we shall therefore study next this organ, which seems to be the food factory of the world.

85. Structure of leaves. The most conspicuous part of the ordinary leaf is broad, thin, and green and is known as the blade. Besides the blade there is usually a stalk, called the petiole, and sometimes also, at the base of the petiole, two little blades, which are called stipules. The petiole is rather strong and woody and serves to hold the leaf blade in the proper position (fig. 40).

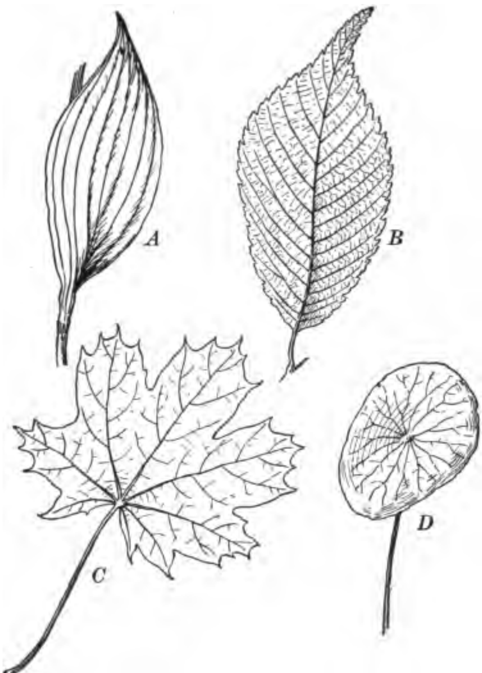

FIG. 40. Types of leaves

A, leaf of the lady's-slipper orchid; *B*, leaf of the elm; *C*, leaf of the maple; *D*, leaf of the water shield

The leaf contains many veins, which serve as a framework to support it as well as for other purposes. In many leaves there is a main vein extending from the petiole toward the tip of the blade; smaller veins branch out from this and extend obliquely toward the edge. Other leaves, like those of the geranium or nasturtium, have no single central vein, but, instead, several large veins extend outward like a fan from the end of the petiole. There are other leaves, like that of the common plantain, in which the principal veins all start from the petiole and run nearly parallel toward the tip of the

blade. The surface layer of the leaf is like a thin skin and is called the epidermis. The green part of the leaf inside the epidermis is the mesophyll. The epidermis is ordinarily as thin as fine tissue paper and almost as transparent. It can be quite easily peeled from some leaves, while on others it is too delicate to be removed. The epidermis is found on petioles and young stems, as well as on the blades.

Although it is so thin the epidermis is able to protect the mesophyll. If it is removed the lightest touch seems to crush the mesophyll and within a few minutes it will begin to shrivel or turn black from loss of water. If the epidermis were not present the mesophyll would soon be destroyed by the whipping of the wind, as well as completely dried.

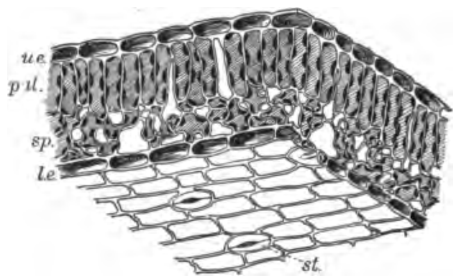

FIG. 41. Diagram of a leaf section

The view shows a part of a leaf, greatly magnified. The lower surface and the cut edge are represented: *u.e.*, upper epidermis; *pal.*, palisade tissue; *sp.*, spongy tissue; *le.*, lower epidermis; *st.*, stoma

86. Structure of the epidermis. It is very plain as you peel it off that the epidermis covers the entire blade, and it is equally certain that air gets into the leaf in some way. Just how it gets in is to be explained by examining the structure of the epidermis, and this must be done with the microscope, for the unaided eye gives us little information on this point (fig. 41).

If a bit of the epidermis from a lily or a blue-flag leaf is examined with a high-power microscope, it will be found that it looks something like a brick pavement. It is made up of many small oblong bodies closely joined together. These bodies are like bricks only in shape and in the way they are joined. They are called cells, and not only the epidermis but

also all the other parts of the plant are made up of cells. The cells differ very much from the bricks with which we compared them. They are transparent and, so far as you can see in the piece of epidermis, they are hollow. The cells contain the living material of the plant, though this is often so transparent that it is difficult to see. Ordinarily we see only the wall which incloses the living part of the cell.

A few of the cells of the epidermis are crescent-shaped or bean-shaped instead of rectangular. These cells are always in pairs, with their concave surfaces next to each other. These curved surfaces do not come together tightly, as the surfaces of all the other cells do, and this leaves a little space between them which is an opening through the epidermis. These openings are called stomata, and the two bean-shaped cells with each stoma are called the guard cells. The guard cells make the opening larger or smaller by changing their shape.

If you look in the microscope the stomata seem to be far apart, but one must remember that the view in the instrument is very much magnified. Perhaps half a dozen stomata are seen, apparently much scattered over a wide surface, but in reality the surface of the epidermis seen under a high-power microscope is not larger than the period at the end of a sentence. It is common for leaves to have more than 60,000 stomata to the square inch, and some leaves have as many as 700,000 per square inch. Most of these are found on the lower surface. It has been estimated that one large sunflower leaf contains 13,000,000 stomata. This great number allows the carbon dioxide to enter freely and much water vapor to escape.

The cells of the epidermis are not always so regular in shape as in the lily. In very many plants they are extremely irregular, though always fitting together very closely. The stomata too vary in shape and appearance.

87. Structure of the leaf interior. The interior, or mesophyll, of the leaf (fig. 41), like all the other parts of a plant, is made up of cells. Each cell has a thin, transparent wall

and includes a semiliquid, clear mass of living substance (protoplasm) and a number of green granules called chloroplasts. The irregular cells near the lower epidermis have large spaces between them and are called the spongy tissue. Its many spaces give the air which enters through the lower epidermis an opportunity to reach all the cells.

The upper green cells are long, narrow, and cylindrical. They stand side by side, with the end of each cell toward the epidermis, and are called the palisade layer.

The green coloring matter, or chlorophyll, does not color the cells green throughout, as one might suppose. In each cell there are found some small, rounded grains that are bright green in color, but the remainder of the cell is quite colorless. The chlorophyll may be removed from the chloroplasts, leaving the leaf white. These chloroplasts are much more numerous in the cells of the palisade than in those of the spongy tissue, so that the upper side of a leaf is usually much darker green than the lower side. It is upon these chloroplasts that the light acts in the manufacture of sugar and starch.

88. Entrance of materials into the leaf. Water, which has been absorbed from the soil by the roots, passes up the stem and reaches the various parts of the leaf through the leaf veins. Those cells which are not in contact with the veins receive water through other cells. The water supply therefore reaches every cell of the leaf.

Carbon dioxide, as well as other components of the air, passes through the stomata by diffusion. The spaces between the cells of the mesophyll allow the gas to spread throughout the leaf. In this way carbon dioxide and water — the raw materials of food manufacture — are brought together in the cells of the mesophyll.

89. Manufacture of carbohydrates. It is in the cells of the mesophyll that a change occurs in the two compounds, water and carbon dioxide, by which sugars are produced and oxygen released.

If the sugar is not needed at once as food for the plant, it may be converted into starch and stored in the leaf to be used during the night, when the plant cannot manufacture food. A part of the sugar is converted into cellulose, which makes up the woody fibers which form the supporting skeleton of the plant. Under the name carbohydrates it is convenient to group sugar and such other substances as starch and cellulose, which are easily produced from sugar by the plant.

90. The waste material. The oxygen produced when sugar is formed is gaseous oxygen exactly like that in the air, and may pass out through the stomata into the air, where it mingles with the other gases. It may be called the waste material of the process of manufacture which we have just been studying. Bubbles of oxygen may often be seen rising from plants which are growing under water. It is escaping from land plants in a similar way, though it is not visible in the air. Some of this same oxygen, or other oxygen, may be used by the plant in its respiration.

91. The source of energy. A factory needs energy; and our carbohydrate factory in the leaf must have energy to operate it. Most factories that we are familiar with are operated by energy derived from a waterfall, or from burning coal under the boilers of a steam engine, or by electric power, but the leaf derives its energy from a source that is different from all these and at first appears rather surprising — the sunlight. Light is as much a source of power or form of energy as is electricity, heat, or falling water, but men have not yet learned so well how to use it. We may cause light to do work on a photographic plate, we know that it will change the colors of the chemicals we use to dye our fabrics, and we may cause it to do other kinds of work for us, but we have not learned how to make it run our factories. The leaf is able to use this energy of light in the manufacture of carbohydrates. If there is no strong light

shining upon the plant, it is not able to carry on this work, and the plant factory stops. For that reason all green plants must live where there is light, and they cannot make starch or sugar at night. Artificial light will answer if it is strong enough, but usually it is too weak to have any appreciable effect.

FIG. 42. Indian pipe — a dependent plant
This plant is wholly without chlorophyll; it secures its food from organic substances in the soil

92. Importance of chlorophyll. It follows from what has been said in the preceding sections that the carbohydrate manufacture can go on only in the presence of light and chlorophyll. This fact causes us to regard chlorophyll as a very important substance. All plants which have chlorophyll are able to manufacture their own food, while plants which do not (figs. 42 and 43) have it are obliged to depend upon securing the food already made. We may call those plants which have chlorophyll independent plants and those which do not have it dependent plants.

The process in which the chloroplasts of green plants, with the aid of light, manufacture carbohydrates out of water and carbon dioxide is called photosynthesis. This is the name of the process we have been studying. It is of very great importance in making the food of the world.

93. Sugar and starch in the leaf. Sugar is commonly formed in the leaf in the process of photosynthesis and is being continually carried away for use in other parts of the plant. On a bright, sunny day it is made much more rapidly than it can be carried away or used, and if there were not some way to dispose of it the sugar would accumulate in the leaf until the sap became so filled with it that the work of the leaf could not go on. The leaf has the power of changing the excess sugar into starch. This removes the excess carbohydrate from the sap, since starch is not readily dissolved in water. By evening, if the day has been a bright one, a great deal of starch is stored in the leaf. At night, when no sugar is being made, the starch in the leaf is slowly changed into sugar by means of a process of digestion. Some of it is used as food for the leaf and some is carried away to serve as food in other parts of the plant, to be stored more permanently as starch in seeds or roots or to be converted into cellulose in the woody stem. The stored food may be taken up and used at a later time.

FIG. 43. Dodder — a dependent plant

The tangled, leafless vine is the dodder. It secures its food from the other plant, which is known as its host, while the dodder is a parasite

94. Comparison with a factory. It may be interesting to sum up the process of photosynthesis by comparing it with a factory. The comparison may be made as follows:

The factory	Green part of the plant
Machinery	Chloroplasts
Energy	Light
Raw material	Water and carbon dioxide
Finished product	Carbohydrates
Waste product	Oxygen

95. Importance of plant synthesis. The food supply of all living things depends upon the work of green plants. Carbohydrates, fats, and proteins make up a very large part of our own food and of the food of many animals. Animals are unable to synthesize these foods from simple compounds. This is just as true when we eat meat as when we eat vegetables. Cattle eat grass and grain and make them over into their own flesh, but they are just as unable as we are to use the very simple substances — carbon dioxide, water, and nitrate — which are used by the plants. The green plants and the work which they do are therefore of the very greatest importance.

96. Manufacture of fat. Although the carbohydrates form a large part of all plants, they are by no means the only substances manufactured by plant cells. We are all familiar with such fats as olive oil, cottonseed oil, and corn oil. Most plants produce such substances and store them in their seeds. Like the carbohydrates the fats contain only carbon, hydrogen, and oxygen and are undoubtedly produced from the carbon dioxide of the air and water. We do not know as yet all the details of how the plant does this.

97. Manufacture of protein. A third group of substances of great importance which are synthesized by plants are the proteins. In addition to carbon, hydrogen, and oxygen, all proteins contain nitrogen and also a small amount of sulphur. Most of the carbon, hydrogen, and oxygen are obtained

from carbon dioxide and water, but the plant cannot secure its nitrogen from the air. The plant uses nitrogen from such compounds as ammonia and nitrates. These are present in good soils and are often added to poor soils as fertilizer. The process by which the plant builds protein cannot be overestimated. Animals are as unable to make protein from simple substances as they are to make carbohydrates.

CHAPTER VIII

DUST, MOLDS, AND BACTERIA OF THE AIR

98. Questions for Discussion. **1.** Is there commonly more dust in the air over cities or over the open country? **2.** What causes milk to sour? meat to decay? fruit juice to ferment? **3.** If milk does not sour when allowed to stand for several days in a warm place, does this indicate that it is of good quality? What might prevent it from souring? **4.** If a bacterium should divide and thus produce two bacteria once in each thirty minutes, and continue to do so for twenty-four hours, how many will there be at the end of that time as the result of the successive divisions? **5.** Why are objects less likely to mold in a house which is carefully and frequently cleaned than in one which is not well cared for? **6.** What is the source of the mold which sometimes appears upon bread if the bread is left for some days in a tightly closed box? **7.** What are the bluish-green patches that appear on gloves or shoes which have been left in a warm, damp closet? **8.** Would surface wells in cities and other densely inhabited places commonly be safe sources of supply for drinking water? **9.** Are the water supplies at summer resorts and picnic grounds in your vicinity safe sources for drinking water? **10.** Should we be able to get on better if there were no bacteria or other organisms which produce decay? **11.** Why should schoolroom floors be cleaned and oiled frequently?

99. Abundance of dust. Dust consists of very small, solid particles which are borne along by the air. The larger particles settle very rapidly, but the finer ones fall through the air so slowly that they remain floating for a long time. If a wind is blowing they may be carried great distances. The abundance of dust in the air becomes obvious when we see a beam of sunlight crossing a darkened room. All the bright points dancing in the light are bits of dust, but most of the particles are too small to be seen in this way. The

fact that a covering of dust soon settles on the furniture which was carefully cleaned but a few hours before is one of common observation. When we go out of doors, dust often gets into our mouths and nostrils, irritates our eyes, and clings to our clothing. Indoors we cannot escape it, for even though we close the house it filters through the smallest cracks. It is upon the food we eat, particularly if we purchase articles from street stands or in stores where the food is displayed uncovered. In cities the air is often so filled with solid particles, whether called dust or smoke, that it is impossible to see very far. Dust is not wholly absent even in the clear air over the desert or the ocean.

100. The sources of dust. What is this dust which we might eat with fruit purchased from a street stand at some dusty corner? Undoubtedly a large part of it comes from the dust of the street, ground up by the hoofs of horses and the wheels of vehicles. A glance into the street will enable us to see some of the things which are being crushed to powder and which will later make part of the common dust as it is picked up by the wind and whirled about. Some particles are bits of unburned carbon (smoke or soot), and in cities this may make up a large part of the dust. Bits of wool and cotton from the clothing of all sorts of people, fragments of hairs from the coats of animals, dead cells from the skins of people and animals — all these things and many more enter into the composition of dust. Some of the dust particles may irritate the delicate membranes of the nose and lungs. A larger particle in the eye may occasion serious trouble. But if these and the household inconveniences were all, we might be inclined to think dust merely an annoyance.

101. Living dust. We shall get some more information about these particles in the air if we will perform certain experiments. Cut a slice from a fresh loaf of bread, using a clean knife. If this slice is exposed to the air for a while and then covered up in such a way that it cannot get dry,

within a few days it will be covered with a growth of fine, white threadlike bodies and will exhibit the appearance of the growth to which we apply the name mold. Mold is a living plant, but in appearance it is quite unlike ordinary plants.

In a few days the mold produces small black heads which yield a fine, dustlike black powder. These dustlike particles are called spores. Spores are easily blown about by the wind, and if one of them alights upon a piece of bread or in any other favorable place, it is able to grow into a new mold plant.

Again, if a weak solution of sugar in water is exposed to the dust of the air and allowed to stand for several days, it ferments; that is, bubbles of gas rise through the liquid. This gas is carbon dioxide. The sugar can no longer be found in the solution, but in its place there is a small amount of alcohol, and a peculiar odor is present. A scum collects at the surface of the liquid and probably at the bottom also (fig. 44). The microscope shows that this scum is made up of minute, living yeast plants.

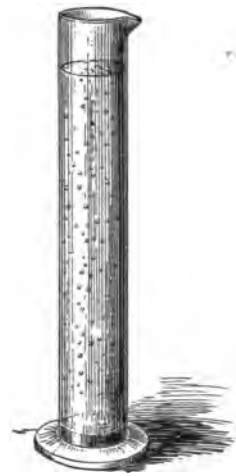

FIG. 44. Fermentation by yeasts

Yeast plants were placed in the sugar solution within the jar. Bubbles of gas formed by fermentation rise through the solution, and large numbers of yeast plants settle as sediment at the bottom

102. Tests for living materials. If a sugar solution is boiled in order to kill any yeast that may be in it, and is then inclosed so that no yeast can enter, fermentation will not occur; but if the solution remains exposed to the air after boiling, fermentation will follow. This shows that the yeast gets into the solution from the air and that it is one cause of fermentation.

If a thin layer of beef broth or similar substance which is stiffened with gelatin or agar is poured into shallow dishes,

another interesting experiment may be performed. The material must have been heated to destroy any living things that may have been in it. One of these dishes should be uncovered to the dust of the air and allowed to remain so for perhaps fifteen minutes, and then covered again; the other dish should not be uncovered at any time. After several days it will be found that the gelatin in the dish which was exposed to the air has upon it a number of small round spots (fig. 45) which are usually colored white but are sometimes pink, orange, or yellow. These spots will enlarge from day to day. They consist of millions of very minute objects which can scarcely be seen even with the aid of the microscope. These are living plant cells of the simplest structure and are called bacteria. Each of the bacterial colonies has resulted from the multiplication of one or a few bacteria which fell upon the gelatin when it was exposed to the air.

FIG. 45. Colonies of bacteria

Each of the circular or irregular patches represents one colony of bacteria. The bacteria grew in a thin layer of nutrient agar. The dish is 9 cm. in diameter and contains 350 colonies of bacteria. The colonies have arisen from the multiplication of bacteria which fell upon the agar during fifteen minutes' exposure out of doors

Therefore we learn from these experiments (1) that a part of the dust of the air consists of things that are able to grow and multiply if they happen to alight upon favorable substances; (2) that there are at least three kinds of living

things represented in the air — bacteria, yeasts, and mold spores; (3) that each of these is able to grow vigorously if only it falls on the right kind of substance; and (4) that all of them are so numerous that they are likely to fall upon every favorable place and, of course, upon unfavorable places as well.

103. The dependent plants. In a preceding study we saw that green plants take their food from carbon dioxide and water. There are some plants that are not green; that is, they have no chlorophyll. Such are the mushrooms and molds. They are therefore unable to make their food and are obliged to secure it from other plants or animals. Since these plants depend upon other living things for their food, they are called dependent plants. Some of them secure food from living plant or animal bodies and are called parasites (fig. 46). Others live upon the material secured from the dead bodies of plants and animals or upon materials formed by plants and animals. These are called saprophytes. The common mushrooms live and grow in soil in which pieces of dead leaves, decaying wood, and bark are mingled, and it is from this

FIG. 46. Corn smut — a parasitic plant

This parasite grows in the corn plant and produces masses of dark spores which may appear on the ear, stalk, or leaves of the corn

material that they secure their food. Therefore the mushroom is a saprophyte (fig. 47).

A great many kinds of parasites and saprophytes exist, and some of them, particularly the parasites, cause great damage to our crops. Some of the bacteria are saprophytes, while others are parasites. The host on which parasitic bacteria live may be either a plant or an animal.

FIG. 47. A common mushroom — a saprophytic plant

This mushroom grows upon decaying plant and animal materials

104. Size and growth of bacteria. Bacteria are the smallest of living things, often measuring not over $\frac{1}{500000}$ inch in diameter. Some kinds are considerably larger than this, while others are much smaller (fig. 48). Only the very highest powers of the microscope will give information about their internal structures, and there is good reason to believe that there are bacteria so very minute that they are quite invisible even with the best microscope.

New bacteria are produced by division of the old ones. After one has grown to adult size it may divide into two, each of which may continue to grow and divide. The division may be repeated as often as once in every twenty minutes, though usually not so frequently. Like other dependent plants, bacteria feed upon and destroy plant and animal materials and, on account of the rapidity with which they multiply, are usually found in very large numbers.

FIG. 48. Photomicrographs of bacteria

These photographs were taken through a high-power microscope. The small, dark bodies are the bacteria, very highly magnified. Photographs by Dr. N. M. Harris

105. Study of yeasts, molds, and bacteria. The study of these forms of life is of great importance, and the methods that must be used in studying them are different from those used in studying larger plants. One who wishes to know much about them must give his attention to this branch of science alone. On account of the danger to man from disease-producing bacteria, the science of bacteriology has been taught largely in connection with the study of medicine, but its importance in other respects is coming to be more commonly recognized. Yeasts and molds have little relation to disease, but are of great importance in daily life and in industry because of the changes which they produce in food.

106. Relation of bacteria to decay. Since it is chiefly bacteria, yeasts, and molds which cause the change known as decay in plant and animal substances, one way to prevent decay is to prevent the growth of these organisms. The most successful methods of preventing harm by bacteria, yeasts, or molds is to kill those present by the use of heat or chemicals and to prevent the entrance of others.

The latter method is sometimes used to preserve milk, formaldehyde being added in small quantities for this purpose. Formaldehyde is effective in preserving the milk, but it is very objectionable in a food material. An interesting and proper use is in preserving specimens in museums. Other chemicals are used in canned goods for the same purpose, but in general it may be said that any chemical which will destroy bacteria is not likely to be a suitable article of food. Most states have laws which prohibit the use of injurious preservatives in food. What are the laws in your state? The preservation of food by means of salt, sugar, or vinegar is a common and effective method. This is practiced in the canning of fruits and other food products. Yeasts and molds are present on the skins of all fruits and sooner or later cause the fruit to spoil unless they are destroyed. In canning, the fruit is first boiled to kill yeast and mold; it is then sealed up air-tight while still hot, in order to exclude all dependent plants; and if both operations have been successful (that is, if there are no living things in the can and no opportunity exists for them to get in) the fruit will keep indefinitely. Yeast and bacteria cannot grow if a good deal of sugar is added to the fruit. It is a matter of common experience that jellies and jams may be kept for a long time without being tightly sealed. This is not a satisfactory protection against molds, however, unless the food is kept in a cool, dry place.

The process by means of which all life of every kind is destroyed by heat, chemicals, or other means is known as

sterilization. The decay of substances may also be hindered through drying or refrigeration. Many foods, such as apples, grapes, plums, peas, and beans, may be kept for a long time if they are dried and kept in a dry place. For other fruits and vegetables the skin serves as sufficient protection for a long time if they are kept in a cool, dry place where there is a good circulation of air. These measures protect against the growth of mold.

107. Bacteria and disease. Bacteria that are able to grow parasitically in the bodies of men, animals, and plants frequently produce more or less serious diseases. In many cases the bacteria are easily transferred from one person to another, and such diseases are said to be infectious. Other bacteria of this class are distributed through the agency of air or water.

Examples of bacterial diseases are boils and carbuncles, blood poisoning, lockjaw, pneumonia, diphtheria, typhoid fever, influenza, tuberculosis, leprosy, cholera, and the plague. Recently we have come to realize that common colds are due to bacteria and are infectious. We should be careful, therefore, not to spread colds by coughing and sneezing.

108. Useful bacteria. Bacteria are of direct use in many manufacturing processes, for instance, in vinegar-making, for the fermentation that produces the sour substance in vinegar is the result of bacterial action. Others of these organisms cause the change in cream known as "ripening," and the flavor of butter is due, in part at least, to this kind of bacteria. In cheese-making the work of bacteria is indispensable, and a large part of the difference in the flavor of the different varieties is due to the different kinds of bacteria which have assisted in the ripening, though some kinds of cheese are ripened by certain molds.

109. Useful yeast. One of the most useful dependent plants is the yeast which is used for bread-making. The yeast feeds on the sugar in the dough and produces alcohol and carbon dioxide. The carbon dioxide is prevented from

escaping by the elastic dough, but stretches the dough and makes the bread light. The alcohol evaporates in the baking.

110. Bacteria in cultivation. On account of the value of certain kinds of bacteria they are sometimes cultivated, in order to have them always on hand. For instance, it has been found that if milk is sterilized and then inoculated with certain kinds of bacteria, the cheese made from this milk will always have the desired flavor, whereas if this is not done the flavor will depend upon the bacteria that may chance to get into it from the air, and the results may not be at all desirable. It is quite probable that in the future we shall domesticate many kinds of bacteria for which we find use.

CHAPTER IX

DISTRIBUTION OF BACTERIA AND OTHER DISEASE GERMS

111. Questions for Discussion. **1.** What disease has caused the most deaths in your community during the past year? How was the disease transmitted from one person to another? **2.** What precautions are taken in your community to secure pure water and milk? **3.** What is your community doing to decrease the number of flies? **4.** Is your home as well defended from flies as it should be? **5.** Is the breeding of mosquitoes about your home prevented? **6.** If impure surface water runs into a well from the top, is it necessary to draw all the water from the well to purify it or only the first few feet at the top? **7.** Why is expectoration on sidewalks and in street cars forbidden? What is your state law on this question? **8.** Why are there laws prohibiting public drinking cups? **9.** Baker's bread is handled by more people before being used than homemade bread. How does this affect the probability of harmful bacteria's being present on this bread? **10.** Which is to be preferred, clean certified milk or ordinary milk which has been pasteurized? **11.** Why is machine-made ice often used in regions where there is much cold weather as well as in regions that are warm? **12.** What are your state laws relative to quarantine in case of infectious diseases? Why should all urge that quarantine laws be enforced?

112. Means of distribution. However great may be the injury which disease germs are capable of doing to each of us, it is clear that no harm can actually result unless the germs are carried by some means from those who are sick to those who are well. It therefore becomes highly important for all of us to know the means of distribution of disease germs so that we may avoid them. We have seen that the air is one means of distribution, but many others exist. Substances upon which bacteria are growing sometimes become dry and powdered, as in the street dust of which we have spoken. The bacteria are then blown about in air currents and, with the remainder of the dust, settle wherever they may.

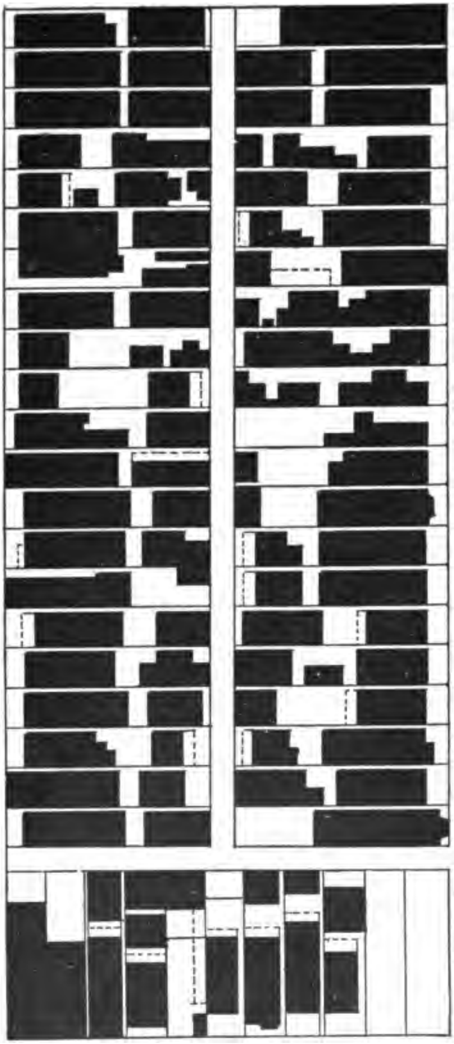

FIG. 49. A crowded city block

The dark areas represent buildings. These buildings house 1600 persons, and in such crowded quarters it is difficult to prevent the spread of disease. After Report of the Department of Health of Chicago

The air is never free from them, although they are more plentiful at some times and in some places than in others. Water is also a prominent agency in the distribution of bacteria and will be discussed in connection with our consideration of water supply.

Certain kinds of disease-producing bacteria are most commonly communicated more or less directly from person to person (fig. 49). Insects are agents of great importance, and investigations of the past two decades have given most interesting evidence regarding the ways in which some of the most destructive diseases are dependent upon them for distribution. The mosquito, flea, and cattle tick are especially bad offenders in this respect.

113. Bacteria upon carelessly handled bread. A special student of bacteriology recently made a careful study of loaves of bread to ascertain how many bacteria there are upon the surfaces of the loaves. He secured bread from various parts of the city and from people who handled and sold it in many ways. He found that unwrapped bread had more bacteria upon it than wrapped bread. From 31 loaves collected from dirty shops the average number of bacteria upon each loaf was 64,970. Of the unwrapped samples 39 per cent had an average of 14,000 bacteria upon each loaf, 39 per cent had an average of 4000 bacteria upon each loaf, and the remaining 22 per cent had an average of 2500 bacteria upon each loaf. Of the specimens of wrapped bread 45 per cent averaged 848 bacteria to the loaf, and 55 per cent averaged 371. Obviously, if the fresh bread is wrapped in clean paper it will be a much less important carrier of bacteria.

Few of the bacteria upon the samples of bread were found to be disease-producing, but unclean bread is not especially attractive, even if its load of bacteria does contain but few that produce disease. It is a notable fact that since the first publication of such studies as that just described, the practice of wrapping bread has become much more common. A careful study of other common food substances which are handled by many persons or not carefully handled might produce equally striking evidence regarding the distribution of bacteria.

114. Protecting ourselves and others. The diseases most commonly transmitted from person to person are those which enter the lungs or alimentary canal through the mouth or nose, such as grippe, diphtheria, colds, tuberculosis, and typhoid fever. Since persons who are well are contaminated through these sources, it is obvious that persons who have the disease must be the source of the trouble. Too much diligence is not possible for the protection of yourself and others.

It is best always to use a handkerchief when coughing or sneezing. Spitting on sidewalks, streets, and in other public places is even worse than spitting in private houses, since less attention is paid in public places to detailed cleaning, and the quick drying of the sputum in the open air rapidly makes it a part of the dust. Hands rapidly accumulate this dust from stair rails, door knobs, pencils, books, and other objects of common use. Protect your mouth against the entrance of everything except clean food and water. Many states have laws regarding the use of public towels and drinking cups and the display of uncovered food. Is this true in your state?

115. Transmission of typhoid bacteria. Within the body of a person who has typhoid fever the number of bacteria may become enormous and may produce such injury as to cause death. But no matter how many typhoid bacteria there may be that affect this person, no other person would catch typhoid from him unless some of the bacteria were transmitted to the second person. Obviously it is of great importance that disease-producing bacteria shall not be transmitted from one person to another. The way to prevent transmission is to make sure that all bacteria from a person who has typhoid fever are promptly killed. This is most difficult, for it is not easy to sterilize everything that might carry bacteria. Furthermore, some people who have recovered from typhoid fever continue to have living typhoid bacteria in their bodies for several years, thus making possible continuous distribution of disease germs.

116. Importance of pure milk and water. Milk and water have often been the means of carrying typhoid bacteria. Many cases show conclusively that when a dairyman or some member of his family has typhoid, many of the people whose milk supply comes partly or wholly from this dairy may take the disease. Lack of care has made possible the introduction of typhoid germs into the milk, and

it is distributed to patrons who unsuspectingly purchase the material which may give them the disease.

If the water and milk are not polluted with typhoid bacteria, or if, when polluted, they are sterilized, they do not

FIG. 50. Bacteria in milk

Each colony was produced by a single bacterium. The upper plate was inoculated with sterilized milk, the left-hand plate with certified milk, and the right-hand plate with ordinary milk. After J. C. Olsen, "Pure Foods"

carry the disease. Milk may be pasteurized (that is, heated for twenty minutes to between 140° and 150° F.), and this kills the typhoid germs. The number of bacteria in a cubic centimeter of milk or water may be very large. There may also be wide variations in the number of these bacteria, due to the different ways in which milk and water are handled

or to the length of time they have been allowed to stand in places favorable to the growth of the bacteria (fig. 50). Thus, in the city of St. Paul, Minnesota, in a special investigation it was found that in samples of milk secured from delivery wagons there were 409,477 bacteria per cubic centimeter, while "dipped store milk" — milk which had been standing in bulk — contained 8,206,000 bacteria per cubic centimeter. In Newark, New Jersey, it was found that "bottled wagon milk" contained 416,000 bacteria per cubic centimeter, while "dipped wagon milk" contained 3,623,333 bacteria per cubic centimeter; that milk delivered to a store

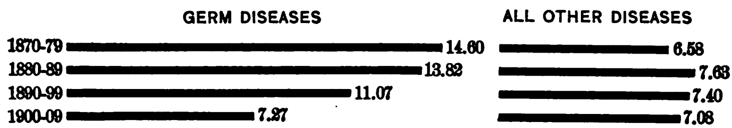

Fig. 51. A comparison of death rates

The diagram shows the number of deaths, per 1000 population, from germ diseases and from all other diseases, in one of the largest American cities. As knowledge and care have increased, the number of deaths from preventable diseases has decreased

contained at the time of its delivery 280,000 bacteria per cubic centimeter, while eight hours after its delivery the number had increased to 1,488,000 bacteria per cubic centimeter. In many cities the law now requires that milk be bottled before distribution.

117. Results of improved hygienic conditions. There are many unquestioned instances of lowering the human death rate through improvement of hygienic conditions (fig. 51). In the city of Chicago, prior to 1908, less than 2 per cent of the milk was pasteurized, and the average death rate from typhoid fever per 100,000 population was 24.8. In the years 1909–1911 between 50 and 75 per cent of the milk was pasteurized, and the average death rate per year from typhoid fever per 100,000 population was 12.4; in 1916 the death rate had decreased to 5.1 per 100,000.

In the city of Boston a better milk and water supply was introduced during the closing decade of the last century and the first decade of this century. In 1910 it was claimed that about one half of the milk used in Boston was pasteurized. In the light of these facts the following table, showing Boston's annual death rate from typhoid fever, is instructive:

REDUCTION OF TYPHOID FEVER IN BOSTON [1]

Year	Typhoid deaths per 100,000 population
1891–1895	31.1
1896–1900	30.6
1901–1905	22.4
1906–1910	16.0
1911	9.0

The average for 1909–1911 was 11.5 per 100,000 population.

118. Results of anti-typhoid vaccination. Although it is highly important to prevent distribution of disease germs, attention should also be directed to important advances in knowledge of methods of treating people so that the disease may not develop even if they are exposed to it.

During the Boer War imperfect attempts were made to control typhoid fever by an antitoxin similar to that for diphtheria, which has saved such multitudes of children. Gradually the method has been improved, so that in 1909 it was recommended in our army as a voluntary protection, and the results were so favorable that in 1911 it was made compulsory. It has been said that it should still be voluntary, but as every case of typhoid fever imperils the health and life of multitudes, we surely have a right to make it compulsory so as to protect all the rest. All that is necessary to prove this is to look at the tables on page 104, of cases and deaths in our army and navy.

[1] Jordan, E. O., General Bacteriology. W B. Saunders Company, 1911.

Typhoid Fever in the United States Army[1]

Year	Cases	Deaths
1906	210	12
1907	124	7
1908	136	11
1909	173	16

Typhoid Fever in the United States Navy

1909	189	17
1910	193	10
1911	222	15

Anti-Typhoid Vaccination made compulsory in the Army and Navy

1912	57	2
1913	22	4
1914	13	0
1915	15	1

The sanitary drainage canal, opened in Chicago in 1900, helped to reduce deaths from typhoid fever. Purer water and better milk, as well as better sewage disposal, have helped. The following table is significant:

Typhoid Death Rate in Chicago after the Opening of the Drainage Canal

Year	Typhoid deaths per 100,000 population	Year	Typhoid deaths per 100,000 population
1900	59.7	1909	12.6
1901	29.1	1910	13.7
1902	44.5	1911	10.7
1903	31.8	1912	7.6
1904	19.6	1913	10.6
1905	16.9	1914	6.9
1906	18.5	1915	5.3
1907	18.2	1916	5.1
1908	15.8		

[1] W. W. Keen, in *Science* (New Series), Vol. XLVII (1918), p. 177.

119. Typhoid bacteria carried by flies. Disease bacteria may be transmitted by many other agencies. For example, typhoid bacteria may live in waste animal matter and may then be carried by flies and deposited upon solid food or in milk or water, and later gain entrance to the human body. The flies are not causes of disease; they are merely the agents of transmission. If no typhoid bacteria had been allowed to get to the organic matter upon which the flies fed, they could not have carried them. Since many people are so careless as to allow distribution of disease bacteria to places from which flies may carry them, it is important that we should study the habits of the fly, with the hope of preventing further distribution of bacteria (fig. 52).

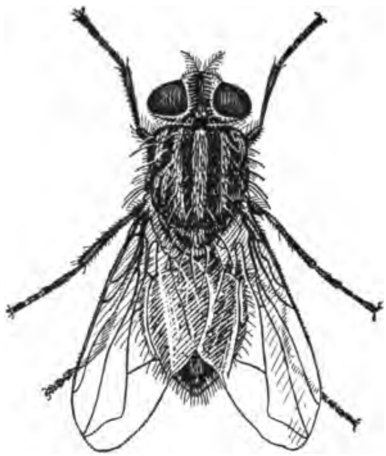

Fig. 52. The house fly

The rough and hairy body of the fly is well adapted to carrying bacteria. After Howard

120. The life history of the house fly. An individual house fly lays about 120 eggs. They are usually laid in horse manure, but they may be placed in any animal or plant refuse. The eggs hatch in from six to eight hours, forming larvæ. The larvæ (fig. 53) are small, white, wormlike creatures called maggots. For about five days they feed upon the refuse in which the eggs were laid, after which they become quiet and change into pupæ. After five or six days the pupæ transform into adult flies. In a few days these flies lay eggs, and another generation is begun. In ten days 120 flies may develop from one pair of house flies. Suppose that half the flies of the second generation are females and that they lay eggs within

two days. At that rate how many flies might be produced from a single pair during four summer months?

121. How house flies carry bacteria. The mouth and feet of the house fly are covered with small, roughish hairs which, when magnified under a lens, show clearly that many bacteria may lodge there as the fly walks upon the refuse which usually forms its food. The bacteria may be deposited from the fly's feet upon any food or any person upon which the fly may alight. Some of the bacteria are swallowed by the fly

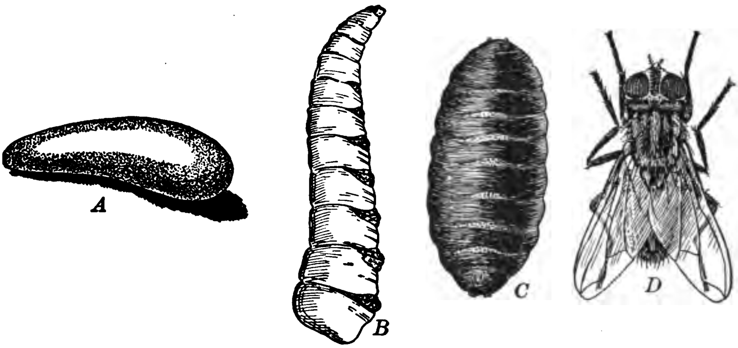

FIG. 53. Stages in the life of the house fly
A, egg; *B*, larva; *C*, pupa; *D*, mature fly

and may later be excreted and deposited at its next lighting place — perhaps upon someone's food. The transmission of bacteria by the feet of flies is shown in the illustration on page 107.

122. Disposal of house flies. House flies may be disposed of if a little attention is given to the matter. If the refuse in which they lay their eggs and in which the larvæ live is removed, no new crops of flies can be produced. Traps may be so arranged as to catch adult flies, after which they may easily be killed. Obviously coöperation is needed to eliminate this insect, for so long as any person in a community supplies the materials for the growth of flies, just so long will that

community have flies. It is also to be noted that people who will leave refuse exposed so that flies breed in it are likely to be the kind of people who would allow disease bacteria to get into the refuse, thus making possible their further distribution by flies. If no disease germs were allowed to get into the refuse, the increased number of flies would be annoying, but not necessarily of any importance relative to disease.

123. Cleanliness and disease. Individual and civic cleanliness are important. Our standards of taste and of decency should demand that sewage, garbage, and all kinds of refuse be removed at proper times and in proper ways. But vastly more important is the care which will insure that disease germs may not be allowed to pass to other people. When, in 1898, the United States took possession of Havana, Cuba, the harbor, naturally one of the finest in the world, was filled with refuse from Havana. In the city open sewers carried bacteria-laden sewage, and flies, mosquitoes, dogs, and rats had ready access to this filth. During the year 1898 one human being in each twelve died — the terrible price that ignorance and carelessness exact. Our army had

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FIG. 54. Bacteria carried by a fly

A plate of agar culture medium over which a fly was allowed to walk. Colonies of bacteria have developed where the fly touched the culture medium

vanquished the Spanish, but a far more difficult conquest remained. It is easy to locate and fight a political enemy, but it is very hard to fight ignorance, especially when it is backed by unfounded prejudice. Consequently the Cuban of Havana, who had been set free from Spain, had to be set free from himself. Martial law prevailed until the harbor was cleaned, a new and pure water supply was found, a more sanitary system of sewage disposal was installed, and last, but greatest, those who were in charge of sick people were compelled to sterilize all material containing disease bacteria, so that the agents of transmission did not carry disease germs. Soon average health returned to Havana — a conquest of more import than her release from Spain.

124. Malaria caused by an animal organism. The mosquito, like the fly, is a carrier of disease germs, but in this case only certain kinds of germs are transmitted, while almost any kind may be carried by the fly. Malaria is the most common disease the germ of which is carried by mosquitoes. In order that we may understand the relation between mosquitoes and malaria and know how to prevent the latter, we must discuss both the disease and the mosquito. When a person has malaria, his red blood corpuscles are more or less infected with an extremely small one-celled animal. One of these malarial organisms lives within a red corpuscle for a brief period (three days in the case of one kind of malaria), and by the end of that time has undergone repeated divisions, resulting in the formation of several of the one-celled animals. The wall of the corpuscle breaks, and all the newly formed malarial parasites are set free in the liquid of the blood. It is usually just after many such parasites are set free in the blood that the paroxysm known as malarial chill ensues. The germs may enter other red corpuscles, and in due time another crop of their kind will have been produced and another chill ensue. We must discuss the life history of the mosquito before continuing the discussion of malaria.

125. The life history of the mosquito. Mosquito eggs are laid in little groups on the surface of the water (fig. 55, *A*). When the eggs hatch, the individual emerging from each egg is a little squirming insect-like creature, technically called a larva but popularly known as a "wriggler" (fig. 55, *C*). The eggs may hatch in less than a day after they are laid. The larvæ live about seven days in warm weather, but longer if the temperature is cool or if food is scarce. Finally, each larva changes into another form, the pupa (fig. 55, *F*), which lives in the water three days or more. The pupa changes into an adult mosquito. The adult lives in the air, but lays eggs on the surface of the water. When the eggs are produced, another life cycle is begun.

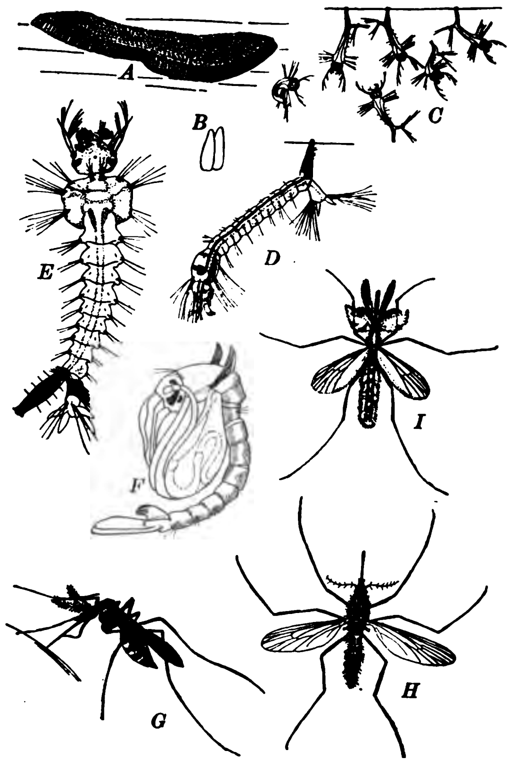


FIG. 55. The common mosquito (*Culex*)

A, egg raft; *B*, eggs; *C*, young "wrigglers," or larvæ; *D* and *E*, views of larvæ; *F*, pupa; *G* and *H*, females; *I*, male. *A*, *B*, *C*, *G*, *H*, and *I*, somewhat enlarged; *D*, *E*, and *F* very much enlarged. After Howard

In its larval stage the mosquito feeds upon very small living things in the water. It frequently comes up and protrudes

through the surface of the water small tubes by means of which a fresh supply of air is gained. The adult female mosquito may secure its food by biting through the skin and sucking the blood from man or other higher animals.

126. How the mosquito carries malaria. When a mosquito of a certain kind (*Anopheles*, fig. 56) feeds upon human blood, it injects a small amount of salivary fluid into the wound

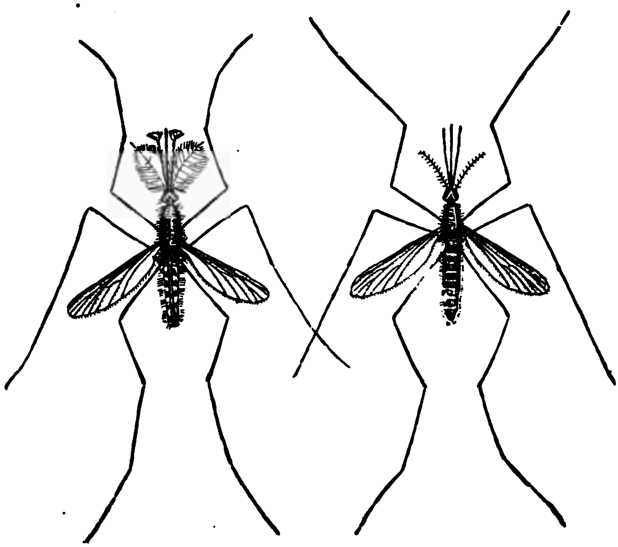


FIG. 56. The malarial mosquito (*Anopheles*)
Male at left; female at right. After Howard

that it has made. If the person has malaria, the mosquito secures blood which may carry malarial germs; and if these germs are present they multiply rapidly within the mosquito, really living in a way quite different from their life in the human blood. Some of the germs get into the mosquito's salivary glands. When the infected mosquito bites a second human being, germs may be injected into the wound with the salivary fluid. These may produce the disease in the person thus infected who has not previously had it.

127. How to destroy mosquitoes. Since malaria and some other diseases are carried only by mosquitoes, it is evident that if we can remove the mosquitoes we shall be free from danger of infection. These insects pass the early part of their lives in ponds, lakes, and quiet water, and they cannot reproduce if the water is drained away. Where such drainage is possible, it is a good method of guarding against the diseases carried by mosquitoes. Another method of destroying these insects is to pour kerosene over the water. The oil

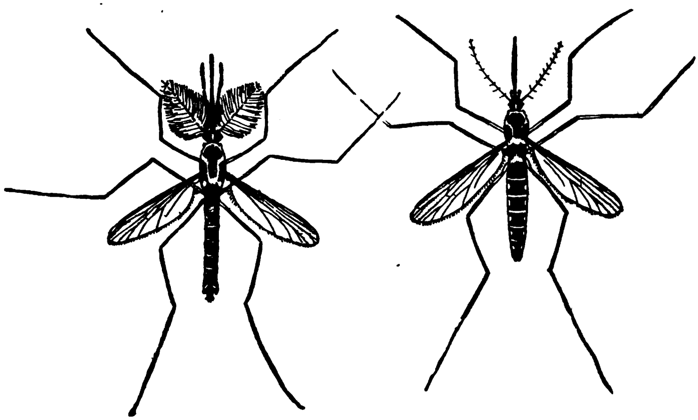


FIG. 57. The yellow-fever mosquito (*Stegomyia*)
Male at left; female at right. After Howard

spreads over the surface of the water and kills the eggs. The larvæ and pupæ cannot secure air through the surface film of oil, so they die; the adults cannot get to the surface of the water to lay more eggs, and if they get into the kerosene in their attempt to lay eggs they get killed. Still another method of getting rid of them is to subject them to their natural enemies. Fish eat the larvæ, and therefore the mosquitoes will be less abundant if the ponds are stocked with fish. A very small body of water, such as that in an old tin can or in a partially filled hoof print, may be ample for the

development of a crop of mosquitoes, and it is necessary to give attention to such places in order to avoid danger.

128. Different kinds of mosquitoes. There are several different kinds of mosquitoes. Only one of these, the genus *Anopheles*, carries the malarial germ. Our most common mosquito (*Culex*) does not, so far as we know, carry any disease germ. Yellow fever is produced by another animal germ, carried by the mosquito known as *Stegomyia* (fig. 57).

129. Disease germs distributed by other insects. House flies and mosquitoes are not the only insects that transmit diseases. It is known that the germs of bubonic plague are transmitted from person to person by a kind of flea that commonly lives upon rats. Rats are subject to the plague, and when they die from it the infected fleas leave their bodies and find new hosts. If they alight upon the body of a human being, their bites will probably infect the person with the plague bacteria. Very obviously the disease is much less likely to attack the careful and cleanly person, living in a well-kept dwelling, than it is to attack his less cleanly, vermin-infested neighbor. The only complete protection from this disease and others possibly carried by rats is to be secured by the total destruction of the rat population. The facts mentioned above explain how it is that in such a country as India the natives may die of the plague in great numbers, while their European neighbors, with cleaner surroundings, usually escape. During the Middle Ages, when all dwellings, from the hovel of the peasant to the palace of the king, were unsanitary and infested with vermin, epidemics of the plague and other diseases frequently swept Europe, but in modern times nothing of the sort is likely to occur in enlightened nations.

Various other insects, such as bedbugs, roaches, and certain flies, have been accused of carrying different diseases. The very deadly spotted fever is carried by a tick, and another tick carries the Texas fever of cattle.

PART II. WATER AND ITS USES

CHAPTER X

ICE, WATER, AND STEAM

130. Questions for Discussion. **1.** Why is it that your breath can be seen in cold air and not in warm? **2.** How hot is boiling water? Can you heat it past the boiling point? **3.** Why do campers on high mountains experience difficulty in cooking food? By what methods can foods be cooked in such places? **4.** Can water possibly be made to boil at less than 100° C.? Is there any advantage in this? **5.** Will water boil at the same temperature if something is dissolved in it? **6.** In cooking potatoes by boiling, can the time of cooking be materially shortened by using a hotter fire after the boiling has started? **7.** What common animals are cooled by perspiration? Name several that are not cooled by this means. **8.** May there be evaporation from a snow bank during cold weather? **9.** Why is hot weather less oppressive in dry regions than in moist ones? **10.** Why is it undesirable to sit in a draft of air immediately after vigorous exercise? **11.** Why are alcohol baths used in cases of fever? **12.** How does a thermos bottle keep hot things hot, and cold things cold? **13.** What advantages from cold-storage plants have resulted to city populations? to country populations? **14.** Why are your feet colder when you are standing in melting snow than when you are standing in freezing snow?

131. When water freezes. What happens when water freezes? Perhaps most of us have observed nothing more than that when water gets cold it changes into a solid, and when it becomes a solid it may break the containing vessel. The temperature at which water freezes is, under ordinary circumstances, always the same. In making the centigrade thermometer the freezing point of water is taken as the starting point in making the scale, and that point is called zero. What is the freezing point on the Fahrenheit thermometer?

If a quantity of water in liquid form is cooled slowly, it will be found that as it cools it contracts. Perhaps that is as we should have expected, since most substances contract when cooling. As the water approaches the freezing point, however, it begins to expand, and very quickly expands more than the whole amount that it has contracted in cooling. After it has become solid, if it is cooled still more it continues to contract, but it never contracts to so small a volume as it had when it was a liquid. See if you can determine for yourselves the temperature at which water begins to expand and that at which it freezes.

The temperature during freezing behaves almost as peculiarly as the volume. If the thermometer is observed during the experiment, it will be found that the temperature falls regularly until the water begins to freeze; it then remains stationary until all the water is frozen, after which it begins to fall again. If a substance (salt or sugar, for instance) is dissolved in the water, the freezing point is much lower — just how much lower depends upon the amount of the substance dissolved.

132. Changing water to steam. When water is heated over a lamp or a stove, it finally gets so hot that some of the water nearest the flame (that is, at the bottom) is changed to steam. The steam rises in bubbles through the remaining water, and the bubbles burst at the surface. The disturbance is called boiling (fig. 58).

The temperature at which boiling begins is called the boiling point. On the centigrade scale this point is 100°. What is it on the Fahrenheit scale? After a mass of water has reached the boiling point, its temperature does not rise as long as any of the water remains in the liquid form. In your experiment you will find the boiling point somewhere near 100° C., but it is not probable that it will be exactly that. The boiling point is raised if solid substances such as salt or sugar are dissolved in the water.

FIG. 58. How water boils

Note the bubbles rising through the water and the steam issuing from the tube. The steam is transparent when it is in the flask and also when it issues from the end of the tube

The boiling point is affected by changes in air pressure. If the air pressure is 30 inches on the barometer, the boiling point of pure water will be 100° C.; if the pressure is greater, the boiling point will be higher; and if the pressure is lower, water will boil before it is as hot as 100° C. To most of us this makes little difference, but to people who live on the mountains it is sometimes a serious matter. In elevated places the air pressure is less than that near the sea level, and the boiling point is lower. On the top of Mont Blanc the boiling point of water is only 84° C.; at the city of Quito, Ecuador, it is 90° C.; and at many places in our own country the same condition exists (fig. 59). When you boil eggs or potatoes it is the heat and not the boiling that cooks them. If you cannot get water hotter than 90° C., for instance, it will take very much longer to cook food materials; and if the temperature is too low, it may be quite impossible to cook certain foods. This, of course, applies only to those foods that are cooked by boiling. When we wish to be sure that foods are not heated above 100° during cooking, we often cook them in a double boiler or steamer to make sure that the only heat they get comes through the boiling water so as to prevent burning.

Increased pressure raises the boiling point very decidedly. In the steam boiler, where steam is not allowed to escape until it has reached a high pressure, the pressure of the steam has the same effect upon the boiling point as does the increased pressure of the atmosphere. The boiling point under additional pressure of 30 pounds to the square inch is 120.6° C., at 100 pounds it is 155° C., and at 300 pounds it is 180° C.

Fig. 59. Boiling point upon a mountain

Mount Rainier, Washington. The figures show boiling points (Fahrenheit scale) at different elevations when the air pressure is thirty inches at sea level

133. Other facts about steam. When water changes into steam, it increases enormously in volume if it is free to expand. Steam at atmospheric pressure may occupy about 1600 times as much space as the liquid water from which it was formed. Since steam occupies so much more space than water, a similar volume of it is correspondingly lighter. It is in fact lighter than a similar volume of air. If water is boiled in a closed vessel (as in a steam boiler) the steam cannot expand; but as the temperature increases, the pressure also increases, and finally the steam finds some way of

escape, either by breaking the boiler or through some means provided for its escape, as through a safety valve. This power of expansion is utilized by means of the steam engine.

Steam is a transparent, colorless gas. When steam escapes into the air, there is always a white cloud. This cloud is not steam. The steam quickly cools to a temperature near that of the air, and this is so much below the boiling point that the steam returns to the liquid form. The white cloud is made up of many small drops of liquid water.

It may be observed that the steam which emerges from a teakettle in which water is boiling is transparent as it passes from the end of the spout. In this transparent area the steam has not yet condensed (fig. 58).

134. The usual states of matter. In previous work we have seen that the same substance may occur in solid, liquid, or gaseous form. This is noticed more frequently in the case of water than with any other common substance, but it will be worth while, in the following study of water, to remember that many of the things which are true of it are true of other substances also. We need to be clear about the names which are used for the different states of water. The liquid form is most commonly found, and to this form the name "water" is especially applied. It must be remembered that when liquid water evaporates (thus passing into the form of gas) or when it freezes (becoming a solid), it does not cease to be water. For instance, although the water contained in the air is a gas, usually called water vapor, we may speak of it as water; and when water is a solid we call it ice; but it is water whatever its form may be.

135. Distillation. Formerly it was customary for ships to carry with them enough fresh water to last throughout the voyage, but some steamships now prepare their daily supply from the salt ocean water by distillation. When water containing salt or other solid impurity is boiled and thus evaporated, the solid does not evaporate. Since the steam

does not contain the impurity, it condenses into pure water. The process is called distillation. This is the most certain method of securing pure water (fig. 60).

Large distilling plants are employed to produce commercial supplies of pure water for drinking purposes, for ice manufacture, and for other uses; and in private establishments and in laboratories smaller plants are sometimes maintained.

136. Use of thermometers in candy-making. The fact that sugar dissolved in water raises the boiling point has an

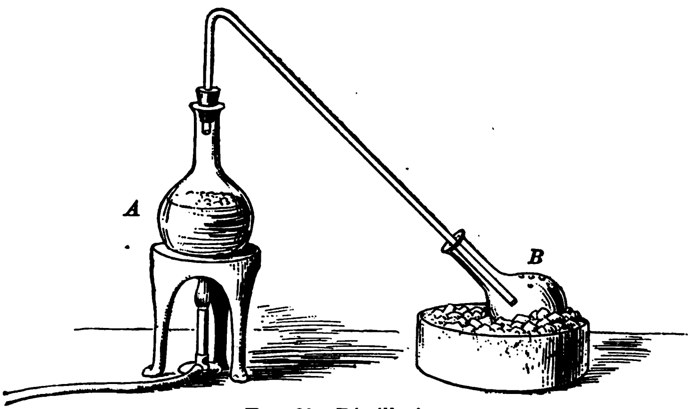


FIG. 60. Distillation

The solution to be distilled is placed in *A*; the steam which passes through the tube is condensed in *B*, which may be cooled with ice or snow

interesting application in candy-making. The temperature at which the sirup boils depends upon the amount of sugar used. If we know from experience at what temperature to stop the boiling to get candy of the desired texture, we can get much more certain results by always using a thermometer. Temperatures at which boiling should stop are as follows:

	Degree Centigrade	Degree Fahrenheit
For fudge and similar candies . .	115°	240°
For taffy and pulled candies . . .	149°	300°
For peanut brittle	154°	310°

137. Boiling and melting points. Every substance has its boiling and melting point, but these may be at temperatures very different from those of water. The approximate melting and boiling points of a few substances are given below:

	Melting Point in Degrees C.	Boiling Point in Degrees C.
Air	—	– 185.
Alcohol	– 130.5	78.
Ammonia	– 77.	– 33.
Benzene	5.4	80.4
Carbon dioxide	– 78.	– 57.
Cast iron	1200.	—
Copper	1083.	2100.
Ether	– 117.	35.5
Hydrogen	– 259.	– 252.
Lead	327.	1525.
Paraffin	55.	400.
Platinum	1755.	2450.
Sulphur	114.	445.5
Water	0.	100.

Excepting for differences in temperature, most substances behave very much like water in changing from solid to liquid and from liquid to gaseous condition. There is one important exception, however. Few expand at the time of freezing, as water does, and these few expand much less.

Substances such as glass and wax do not have a definite melting point. They gradually soften, becoming first like a very thick liquid, and finally flow freely.

138. Evaporation. Even when the temperature of water is not high enough to cause it to boil, the water changes into vapor, but not rapidly. This is shown by the drying of wet objects when exposed to the air. Water will slowly change into vapor (evaporate) at any temperature. Even if water is frozen, evaporation continues. This is shown when wet clothing is hung out of doors on a cold day. It immediately freezes, and remains frozen until it has become dry by evaporation of the frozen water.

The rate of evaporation depends upon several factors. For instance, it is commonly known that things dry more rapidly when the air is warm than when it is cold and that drying is assisted by wind. Rapid evaporation is favored by high temperature, dry air, and winds.

139. Cooling effects. If one stands on the beach in wet clothing after bathing in a lake or in the ocean, he soon becomes chilled, even though it is a warm day. He is chilled more when the wind is blowing than when the air is quiet. When the clothing has become dry, the air seems warm again. One is cooled as long as water is evaporating from the surface of his body or from his clothing. Whenever water or other liquids evaporate, the temperature is lowered; and the more rapidly evaporation occurs, the more the temperature is lowered.

When water boils, considerable quantities of heat are used. If heat is supplied more rapidly, it results in the more rapid formation of steam, but there is no change in temperature of either the water or the steam. At the end of half an hour's vigorous boiling, a kettle of water will have the same temperature as at the beginning of the period, but the amount of water in the kettle will have decreased. The effect of the heat, therefore, has been to evaporate the water, but it has had no effect upon the temperature. The fire or stove has lost the heat which has passed into the water.

The total amount of heat that disappears when a gram weight of water changes into steam is the same whether the steam forms rapidly, as in boiling, or slowly, as in evaporating from wet clothing. In the latter case there is usually no source of intense heat, such as the fire, and the heat which disappears during evaporation is taken from the water itself and from the surrounding objects. Since heat disappears from the water and its surroundings, they are cooler (fig. 61). In the case of the bather on the beach, the heat which was used in evaporating the water from the wet bathing suit was drawn from the water remaining in the suit and from the

body of the bather, thus giving him the sensation of cold. As soon as all the water had evaporated from the suit this withdrawal of heat ceased and the surrounding air temperatures were felt.

Ether and alcohol evaporate so much more rapidly than water that they feel very cold when poured over the hand. Ether may produce so low a temperature that water will be frozen by its use. Surgeons sometimes use ether to partly freeze the surface of a portion of the body upon which a surgical operation is to be performed, since the frozen tissues are so numb that the pain is lessened.

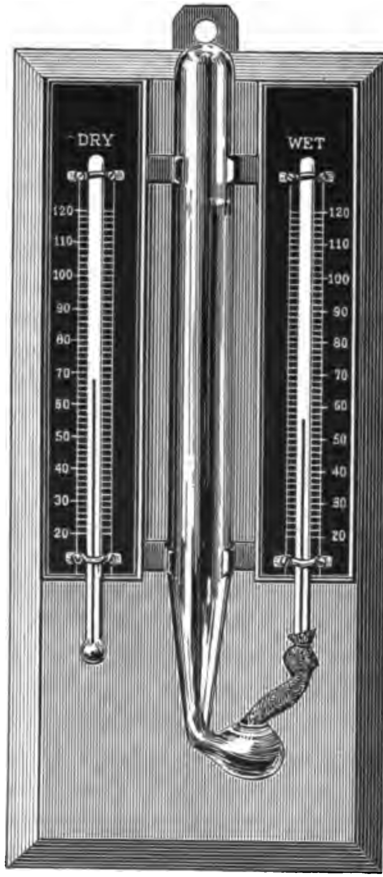


FIG. 61. Wet-bulb and dry-bulb thermometers

The bulb of one of the thermometers is covered with a cloth, which is kept moist by the water in the glass reservoir with which it is connected. Evaporation cools the wet-bulb thermometer, which registers the lower temperature

In many hot, dry countries the water from wells is usually warm and needs cooling. Often ice cannot be had, and other methods of cooling must be adopted. The water is put into porous earthenware jars or into canvas bags, and these are placed where the dry winds can blow over them. The water soaks through the canvas or the porous jar and evaporates so rapidly in the

dry, hot air that the contents of the vessel are made pleasantly cool. Travelers in such regions have learned to cover their canteens with layers of woolen cloth and to wet this at every possible opportunity. So long as the cloth cover is wet, the water in the canteen will be kept cool enough to be palatable. In many parts of the South where ice is expensive iceless coolers are used which work on this same principle. A cage fitted with convenient shelves is covered with cloth which dips into a pan of water on top of the cage. By this device the entire surface of the cloth is kept wet, and the evaporation keeps the air in the cage cool.

140. Ice machines and cold storage. Cooling by evaporation is applied in a practical way in plants for the artificial production of ice and in cold-storage plants. In the operation of these plants advantage is taken of the fact that the boiling point of ammonia at atmospheric pressure (– 28° F. or – 33° C.) is so little below atmospheric temperature that the boiling point can be raised above the usual temperature of the air by increase of pressure (see sect. 132). Thus, while the boiling point is – 28° F. at atmospheric pressure, its boiling point is raised to 80° F. by a pressure of 155 pounds to the square inch.

Figure 62 represents the essential features of an ice-manufacturing plant. The condensing pump forces the gaseous ammonia into the pipes to the right with a pressure of at least 155 pounds to the square inch, and the gas is cooled to the necessary degree by the water which flows over the cooling pipes. The gas therefore condenses into a liquid. This liquid ammonia is allowed to escape through the valve into the pipes at the left only as rapidly as the excess is removed by the pump, and the pressure in these pipes therefore never rises much above 30 pounds to the square inch. The liquid which has escaped into this place of lower pressure immediately begins to change into a gas and, in so doing, absorbs heat from its surroundings. The pipes into which

the liquid ammonia expands are usually surrounded with brine, and this is cooled by the evaporating ammonia several degrees below the freezing point of water. The brine, in turn, cools the water which has been placed in the freezing chambers. The gaseous ammonia passes on to the pump and is used again.

In cold-storage plants the machinery is similar to that used in making ice, but it is used to cool rooms instead of to cool vessels of water. Of course any degree of cold from the freezing point upward can be had, and thus it is possible to store each kind of food in the particular temperature that is best suited to it. Cold storage has made

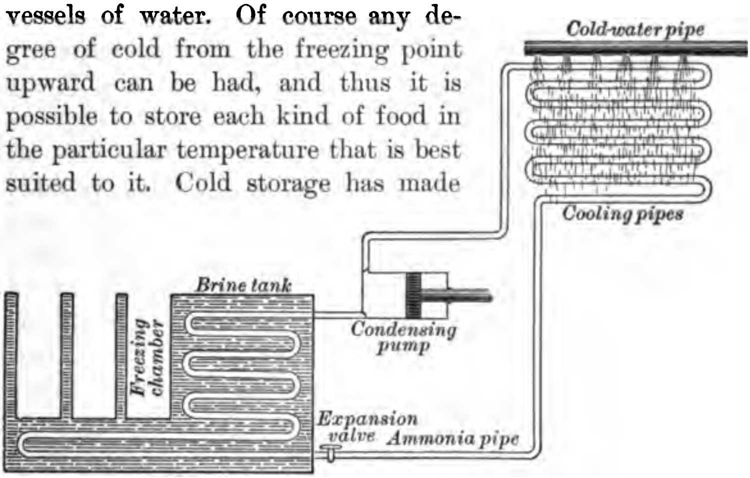


FIG. 62. An artificial-ice machine

possible a supply of fresh foods at seasons when they could not otherwise be obtained. In meat and fish markets brine pipes are often carried along the back of the counters where perishable food is displayed. The cool air, being heavy, does not mix with the air of the store by convection currents. The brine pipes are often white with frost. Why?

141. Perspiration. The bodies of men and of some animals are cooled by evaporation. In the skin there are multitudes of small pores through which water is given off from the body. Usually there is so little water given off that it evaporates as rapidly as it appears, and we do not notice either the water

or the cooling effect of the evaporation. When the weather is unusually warm or when we are making great exertion the perspiration increases so that the body becomes moist and the cooling effect is very evident. If the perspiration were to stop suddenly, we should quickly feel a rise in the temperature of the body. Indeed, that is what happens in a fever.

The temperature of the body ordinarily varies but slightly from normal, which is usually 98.6° F. When we feel hot we

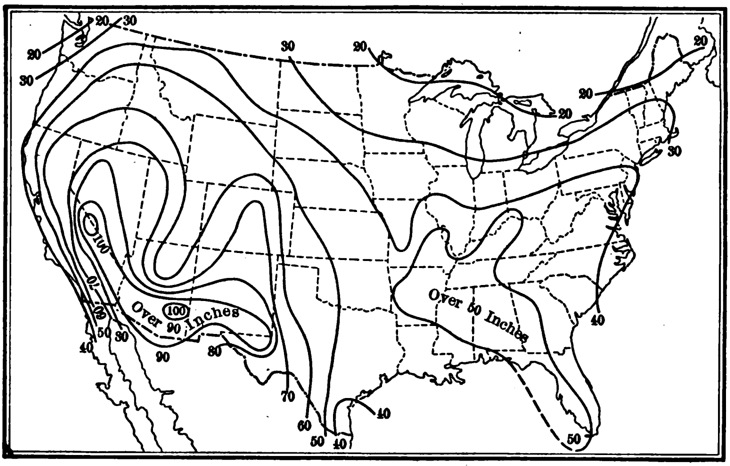


FIG. 63. Rate of evaporation in the United States

The map shows the estimated rate of evaporation in inches per annum. Note the great differences between different parts of the country

are really not much warmer than at other times, as would be proved by a clinical thermometer. The temperature remains constant because the amount of water thrown out for evaporation is regulated by the perspiratory glands. But in case of fever the perspiratory glands cease to work, the skin becomes dry and hot, and the temperature of the whole body rises. If the temperature becomes very high (say 4° or 5° F. above normal), it indicates a serious condition, and death may result.

142. Amount of water evaporated by the air. When we consider that the oceans, lakes, and rivers make up the larger part of the surface of the earth, and that water is evaporating from this surface all the time, it is plain that a very large amount of water evaporates. How much it is no one knows exactly, but we get some idea when we remember that all the water that falls as rain or snow has evaporated from the ocean or from the land.

A study has been made of the rate of evaporation in the United States (fig. 63), and it is believed that about 30 inches of water evaporates each year from the surface of Lake Michigan and about 70 inches from the Great Salt Lake; in some of the desert regions of the Southwest perhaps as much as 100 inches would evaporate annually if there were any body of water there.

FIG. 64. Transpiration by leaves

Some of the water which evaporates from the leaves condenses upon the inside of the bottle

143. Evaporation from plants — transpiration. The evaporation of water from land is greatly accelerated by plants. Trees, grasses, weeds, cultivated crops — in fact, all common land plants — absorb water from the soil, and most of this water may afterwards evaporate from the leaves.

Usually we are not aware that water is evaporating from the leaves of plants, since it passes off as a gas and is therefore not visible. A demonstration of its presence may be made by inclosing several leaves in a bottle or a tumbler (fig. 64) in such a way that there is little chance for water to enter or

leave the bottle excepting through the leaves. The water given off from the leaves soon saturates the space in the bottle, and the excess is deposited on the inside of the bottle. If the leaves are removed from the plant they should be placed with their lower ends in water.

A more satisfactory way to show the loss of water is to weigh a potted plant from time to time, having first wrapped the pot in sheet rubber (Why?). If the area of the leaves is ascertained, it is possible to know just how much water has been evaporated per square inch in a day. It has been found that a good-sized sunflower plant may evaporate as much as a quart of water daily. A large tree will evaporate from 700 to 900 pounds of water on a favorable day, and the grass on a vacant city lot may give off a ton of water in a day.

144. The principle of the refrigerator. As water in freezing does not change temperature until all of it is frozen, so when ice melts, it does not get warmer than 0° C. until all the ice is melted. The heat necessary to melt it is taken from surrounding objects, and so they are cooled as long as the ice is melting. It is on this principle that refrigerators work. In order to economize as much as possible in the use of ice, the walls of the refrigerator are packed with substances through which heat does not easily pass. If the refrigerator is not well built in this particular, so much heat comes into it from the outside that the ice does not lower the temperature in the box very much, and a great deal of ice is consumed. If a twenty-five-pound piece of ice is placed in one refrigerator or in an ordinary wooden box, and the same amount in another refrigerator, and records are kept showing the length of time required for both pieces of ice to melt, an interesting demonstration will be provided regarding the efficiency of refrigerators.

145. Freezing mixtures. Common salt and some other substances absorb moisture very readily. Salt absorbs it so readily that when the humidity of the air is rather high, it absorbs

water even from the air and becomes wet, as all of us have had occasion to notice when using a salt shaker in damp weather. Salt not only absorbs gaseous water from the air but also absorbs water from a piece of ice, thereby changing the ice to the liquid form. This explains why salt is used to melt ice on sidewalks and in other places.

When ice is melted, heat is required to carry on the process. When salt melts ice, the source of heat is the ice and the surrounding air or other objects. If salt and ice are well mixed, the ice will be melted rapidly by the salt, but the temperature of the mixture will not remain at 0° C. It will fall to −17° C. or even slightly lower. The heat needed is taken from the mixture itself, and the presence of the salt prevents the water from freezing at the lower temperature, as it otherwise would do. Such a freezing mixture of salt and ice is often used to produce a temperature slightly below 0° C., as in freezing ice cream.

CHAPTER XI

MECHANICAL USES OF WATER AND AIR

146. Questions for Discussion. 1. What is the principle of drinking through a straw? **2.** A coarse towel was left hanging over the edge of a partially filled bathtub, one end of the towel extending into the water, the other end hanging outside. When it was discovered there was a small pool of water on the floor. How did this take place? **3.** How does a pump lift a liquid? **4.** What is the difference between a force pump and a suction pump? **5.** How is water picked up by a tornado on the sea? **6.** Why does liquid flow from small-necked bottles with a gurgling noise? **7.** Why is it difficult to pour oil into a can steadily if the funnel used fits the opening closely? Why does lifting the funnel help? **8.** How is water forced to the tops of tall buildings? **9.** Why does an iron ship float? How can a submersible boat remain on the surface part of the time and under water part of the time? **10.** Why can a submarine not safely descend to the bottom in the deeper parts of the ocean? **11.** Why are dams commonly thicker at the bottom than at the top? **12.** If an object floats in water almost submerged, how would it behave in oil? in kerosene? in a gas? **13.** What is the principle by means of which a balloon may rise in the air? Is a dirigible balloon heavier than air? is an aëroplane? **14.** How rapidly can an aëroplane ascend? What is the record height reached by an aëroplane? the record long-distance flight?

147. Water transferred by the siphon. The siphon may be used to transfer water or other liquid from one vessel to another over an elevation. This can be done only in case the outlet of the siphon is at a lower level than the surface of the liquid which is being transferred. For instance, in the illustration (fig. 65) the tube, which serves as a siphon, is represented as transferring water from the beaker at *A* to the one at *D*, which is at a lower level. In starting a siphon to work it is necessary to fill the tube with the

liquid. The liquid will flow through the tube if there is a greater force acting in one direction than in the other. In the experiment shown in the illustration the upward pressure in the short arm of the tube is due to the pressure of the air. In the tube at *b* this pressure is equal to the atmospheric pressure minus the downward pressure due to the weight of the column of liquid *ab*. The upward pressure in the tube at *b′* is the atmospheric pressure minus the downward pressure due to the column *b′d*. The force tending to drive the liquid from *A* to *D* will therefore be greater than that tending to drive it in the opposite direction. It will be greater by an amount equal to the difference in weight of the two columns of liquid, corresponding to the height *a′d*. Evidently the siphon will cease to operate if *d* is at the level of *aa′* or if the distance *ab* is greater than the distance the liquid will be raised by the atmospheric pressure. This is about 33 feet in the case of water and about 30 inches in the case of mercury.

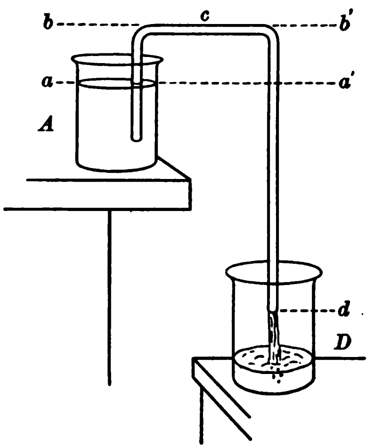


FIG. 65. The siphon

Water flows from *A* into *D* when *d* is below the line *aa′*, if the tube is first filled with water. The water is lifted to the level *bb′* by atmospheric pressure

148. The lift pump. Everyone has seen examples of the common pump which stands on a platform built over a well. When the handle is operated, a stream of water is said to be "lifted" from the well. The structure of a pump is best learned from an examination of the pump itself or, if that is not possible, from a diagram (fig. 66). The essential part of the pump is the cylinder, which is hollow, usually two or three inches in diameter and possibly eight or ten inches in

length. At the bottom it is connected with the pipe, sometimes called the suction pipe, which extends down into the water in the well, and at the top with a pipe leading to the spout, or the spout may be connected directly with the

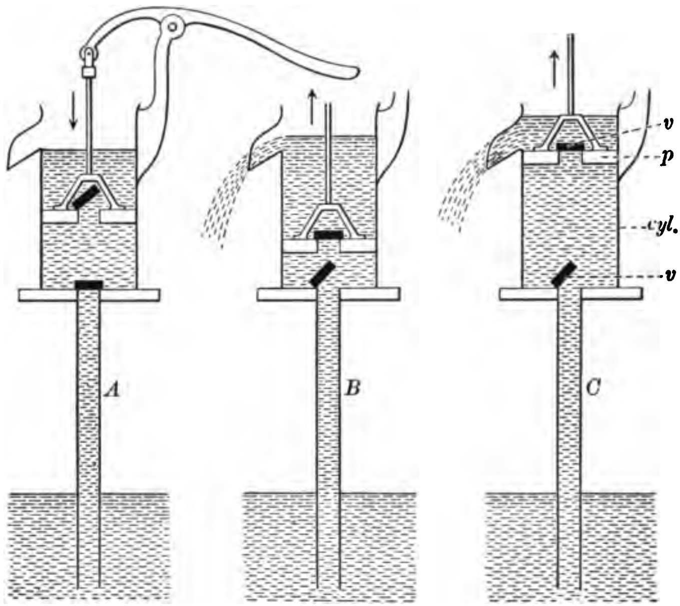


Fig. 66. The lift pump

Three stages of the stroke of the pump are shown: *A*, down stroke; *B*, up stroke; *C*, completion of the stroke. By noting the position in each case of *v* (valve), *p* (piston, or plunger), and *cyl.* (cylinder), the action of the pump may be understood

cylinder. At the bottom of the cylinder, over the opening leading to the pipe, there is a valve so constructed as to allow the water to pass upward but not downward. In the cylinder there is a tightly fitting piston which slides up and down, and in this piston there is another valve which allows the passage of the water upward. Other parts, for example, the handle, may be added for convenience or ease

of operation, but the ones mentioned above are the really essential parts of the pump.

As to the operation of the pump, we may suppose that at the start the cylinder and pipe to the well are filled with water and that the piston is at the top of the cylinder. If the piston is pushed downward the valve in it will permit the water in the cylinder to pass through the piston into the space above it. When the piston reaches the bottom of the cylinder, the water in the cylinder will be above the piston. As the piston ascends it is perfectly clear that the water in the cylinder, which is now above the piston, will be lifted by the piston and perhaps flow out of the spout. When the piston ascends, lifting with it the water in the cylinder, it does not leave the lower part of the cylinder empty. The water in the well flows up the pipe into the cylinder and fills it to the bottom of the piston. Since the piston is above this water, it cannot be said that it lifts the water, for it does not in any way have a hold on the water below it, yet the water rises.

149. Why the water rises in the pump. The rise of the water in the pipe of the pump is due to atmospheric pressure. The atmosphere is pressing downward upon the surface of the water in the well with a force of approximately 15 pounds to the square inch, and this pressure is transmitted to the water within the pipe as an upward force. If the pipe were open at the top the atmosphere would exert the same pressure of 15 pounds per square inch upon the surface of the water within the pipe, and the two forces would exactly counterbalance each other. In that case the water in the pipe would be at rest at the level of the water in the well. Since the pipe is tightly closed by the piston which supports the pressure of the atmosphere, there is no downward pressure exerted upon the water below the piston, but there is an upward force of 15 pounds to the square inch transmitted to it by the water in the well. The atmospheric

pressure will force the water up the pipe and against the piston. If the pipe is too long the water may not reach the cylinder; it will stand at such a height that the downward pressure in the pipe, due to the weight of the water, will be equal to the atmospheric pressure outside. Since, as noted above, the height to which the atmospheric pressure will raise a column of water is about 33 feet, the suction pipe should not exceed this length.

150. Transmission of pressure in liquids. In a squirt gun the pressure which is applied to the liquid by the aid of a piston or a rubber bulb is transmitted to the liquid in the nozzle and shoots the liquid out. In a similar manner the pressure applied to the stopper of a bottle completely filled with water may result in breaking the sides of the bottle. In a city water system the pressure exerted by the pumps at the pumping station is transmitted throughout the system and may be discovered in the pressure of the water at any faucet. The working of many common appliances, such as water motors, lawn sprinklers, and fire engines, depends upon the transmission of pressure by water.

The transmission of pressure by liquids is utilized for the application of great force by means of the hydraulic press. This machine consists essentially of two communicating cylinders, each containing a closely fitting piston, one of the cylinders being of larger diameter than the other (fig. 67). If the diameters of the cylinders are such that the area of the end of one piston is ten times that of the other, it will be found that if a pressure of 1 pound is applied to the water in the smaller cylinder by means of the piston, the pressure exerted by the water against the larger piston will, if friction is ignored, be sufficient to support a weight of 10 pounds; that is, the force exerted by the second piston will be greater than the force applied to the smaller piston by as many times as the area of the larger piston is greater than the area of the smaller one. This rule holds for cylinders and pistons

of any size. Hydraulic presses are commonly used to operate barbers' chairs and some types of elevators and in manufacturing processes in which great force must be exerted, as in baling cotton.

151. The principle of the hydraulic press. In order to understand the principle of the hydraulic press or other appliances in which the transmission of pressure by water is

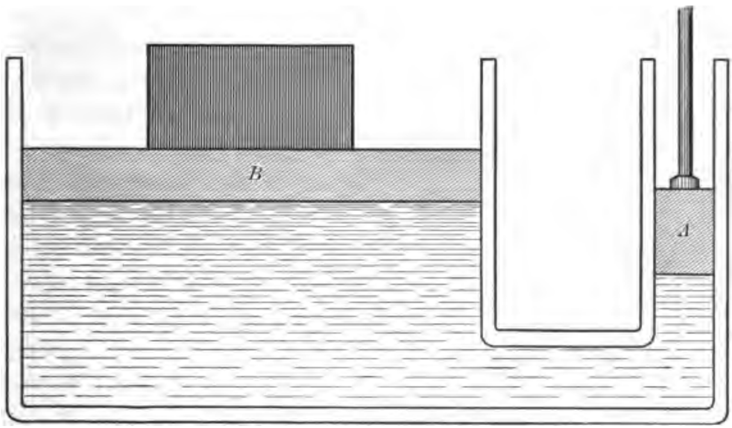


FIG. 67. The hydraulic press

The diameter of *B* is 10 times that of *A*, and its area is therefore 100 times as great. A pressure of 1 gram exerted by *A* upon the water surface beneath it would be transmitted undiminished to each of the 100 equal areas at *B*, and might support a weight of 100 grams at *B*

important, we must attempt to discover the laws of transmission of pressure in liquids. We may illustrate this by means of an aquarium. Suppose the aquarium is filled with water and covered on top and that a pipe leads up through the cover (fig. 68). If, now, we pour into the pipe enough water to fill it to a depth of 1 inch, the total depth of water will be 13 inches and not 12. Since one cubic inch of water weighs 0.0362 pounds, the pressure on a single square inch of the bottom of the aquarium will be 13×0.0362 pound. Since each square inch of the bottom is equally

distant below the free surface of the water, the pressure on each square inch will be the same; that is, each square inch of surface will have the pressure upon it increased by the weight of 1 cubic inch of water. Likewise, the pressure upon each square inch of the sides or top is increased by the same amount. We have put 1 cubic inch of water into the pipe, and its weight presses upon the square inch of the original surface at the lower end of the pipe, with the result that every square inch of the whole interior of the tank receives that much additional pressure.

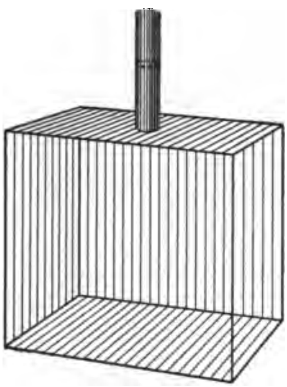


FIG. 68. Pressure in a closed vessel of water

If the pipe is partly filled with water, the additional pressure due to its weight is transmitted to all the walls of the water-filled vessel

When pressure is exerted upon the water in one cylinder of the hydraulic press, this pressure is transmitted undiminished to every equal area of the interior of the apparatus, and therefore to every equal area of the bottom of the large piston. If the end of the small piston has an area of 1 inch, a pressure of a pound exerted here will produce a pressure of a pound on each square inch of the end of the larger piston. The total force exerted by the larger piston will be the sum of the pressures on all these areas, and is therefore as many times greater than the force applied to the smaller one as the area of the larger piston is greater than the area of the smaller one.

In the case of a house supply of water from an elevated tank, the pressure on each square inch of the interior of the pipes or faucets depends upon the depth of the water in the pipes and tank and is exerted equally on every square inch of the interior of the pipe and faucet at any particular level. The violence with which the water will spurt from an open

faucet depends on its distance below the level of the water in the tank and not at all upon its position directly beneath the tank or at one side.

152. Dams. The building of dams in order to confine water or raise the surface to a higher level is very common (fig. 69). They need to be constructed with a great deal of care in order to be able to withstand the weight of water to which they are subjected. The pressure to which a dam will be subjected depends only upon the depth of the water and the area of the submerged part of the dam. A great many lives and much property have been lost by reason of the floods which have been released by breaking dams. One of the greatest catastrophes of this kind was the breaking of the dam near Johnstown, Pennsylvania, in 1889. About two thousand lives were lost in the flood which resulted.

The pressure of the air, like that of water, is due to its weight, but we cannot measure the depth of the air and calculate its pressure as we do with water. We therefore rely upon the barometer, which is, in fact, a pressure gauge, to give us our information about air pressures (see Chapter I).

153. Buoyancy. We are all familiar with the fact that objects appear to be lighter in the water than out of it and that some things float on water. No one has failed to notice this effect when bathing. The floating effect of water may be determined by weighing objects while suspended in the air and again while suspended in water. If we take a cubic centimeter of each of several different kinds of substances that are heavy enough to sink in water, and weigh each in this way, we shall find that each appears to lose 1 gram of its weight when put into water. No matter what differences there may be in the substances, if the pieces are of the same volume they will be buoyed up by the same force. The objects are also buoyed up by a force (1 gram) which is precisely equal to the weight of the volume of water they displace when immersed (1 cubic centimeter). It is found that

Fig. 69. A large dam

This dam was built by the United States Reclamation Service to store water for irrigation. It is 328 feet high and is said to be the highest structure of the kind in the world. Photograph by the United States Reclamation Service

all objects which are immersed in water are buoyed up by a force equal to the weight of the water they displace.

In order to assist in explaining why objects are buoyed up by the water, let us imagine a cube measuring 1 centimeter on each edge submerged beneath the water so that the top is 10 centimeters from the surface (fig. 70). The pressure on each of the four sides will be 10.5 grams, since the average depth of a side is 10.5 centimeters. The pressures on the sides exactly counterbalance each other, and the object is not moved either to right or left. The pressure is 10 grams on the top and 11 grams on the bottom. (Why?) These two do not balance each other. The pressure upward is greater by 1 gram than the pressure downward. Plainly, such an object as we have supposed, if its own weight amounted to nothing, would be pushed up to the surface. If it weighed more than a gram its weight would overcome the upward push and it would descend to the bottom.

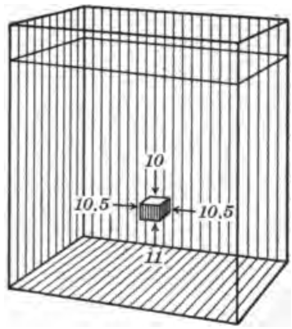


FIG. 70. Buoyancy

If a cube measuring 1 centimeter on each edge is submerged with the top 10 centimeters below the surface of the water, the pressures against the surfaces, in grams, will be as shown in the figure. Note that the pressure against the bottom is greater by 1 gram than that upon the top

154. Floating objects. If an object weighs less than the water it displaces, it will float or, if submerged, will rise to the surface. It will not rest with its top even with the surface of the water, but it will project far enough above the surface so that the submerged part will displace an amount of water the weight of which is equal to its own weight (fig. 71). For example, if the 1-centimeter cube weighed 0.5 gram, it would rise until only one half of it was under water, and it would therefore displace 0.5 gram of water. An iron pail will float on the water because, though it is

made out of very heavy material, it is so shaped that it displaces a great deal of water. The iron ship floats for the same reason. The vessel therefore sinks in the water only deep enough to displace an amount of water equivalent to its own weight.

155. Submarines and balloons. A submarine boat is so constructed that no water can enter it, even if it is wholly submerged, excepting at the will of the occupants. If the occupants wish the boat to dive, water is admitted into special compartments in the interior until the weight of the

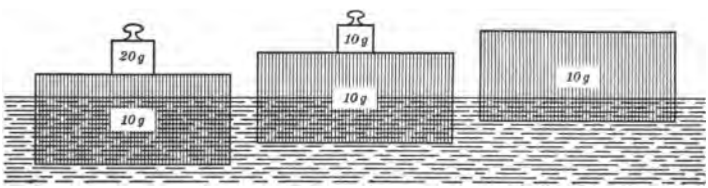


Fig. 71. Floating objects

The object at the right weighs 10 grams and displaces 10 grams of water. When a weight of 10 grams is placed upon it, as in the middle, it displaces twice as much water as at first. When the total weight is 30 grams, as at the left, the displacement is three times as great as at first

boat equals or slightly exceeds the weight of the water it displaces. When they wish to rise to the surface again some of the water is forced out. If the weight of the boat is kept very close to the weight of the water which it displaces, it is possible to steer it to right or left, up or down. The depth to which a submarine may safely descend is limited by the ability of the boat's hull to resist the pressure of the water.

A balloon operates on a similar principle. The bag is filled with a gas that is lighter than the air at the surface of the earth. The air buoys up an object with a force equal to the weight of the air displaced, and, the balloon being lighter than an equal volume of air, it ascends. It will not rise to the top of the air, for the air is less dense at greater altitudes. It rises until it reaches a layer in the air of

such density that the displaced air equals the weight of the balloon and gas, and it remains at that elevation unless something disturbs it. To reach a greater height ballast may be thrown out, and it is possible to descend by allowing the gas to escape. The dirigible balloon may be steered upward and downward in the air, as a submarine may be in the water. As the density of the air varies at different levels, there are limits to the control of the balloon by use of rudders, since the ballast cannot be readily adjusted.

156. Densities. In the preceding paragraphs attention has been called to the fact that an object in the water is buoyed up by a force equal to the weight of the water it displaces. Use may be made of this fact in several ways. We are enabled to determine the volume of irregular objects by this means, for it is evident that if an object loses 5 grams of weight when immersed in water, it must displace 5 grams of water. But water weighs 1 gram per cubic centimeter, and it therefore takes 5 cubic centimeters of water to weigh 5 grams. The object must have a volume of 5 cubic centimeters in order to displace 5 cubic centimeters of water.

The facts regarding buoyancy are useful also in enabling us to find the densities of different substances. By density is meant the weight of a unit volume of a substance — one cubic inch or one cubic centimeter. We might secure the weight of one cubic centimeter of iron by cutting a cube of that size and weighing it, but this would be a difficult process. Instead, we can take any irregular piece of iron, weigh it in the air and again in water, and from the weights calculate its density. The loss of weight in water is equal to the number of grams of water displaced and is therefore equal to the volume. The weight in air divided by the volume equals the weight per cubic centimeter, or the density. The density in ounces per cubic inch can also be secured, but the process is less convenient for use, and the density in grams per cubic centimeter is practically always used.

In the case of liquids the density is usually ascertained by weighing a measured quantity of the liquid.

Below are given a few common substances with their densities.

TABLE OF DENSITIES FOR REFERENCE

(Grams per cubic centimeter)

Alcohol	0.8	Glass	3.4	Olive oil	.9
Aluminium	2.7	Gold	19.4	Pine wood	0.6
Brass	8.4	Ice	0.9	Platinum	21.7
Coal	1.8	Iron	7.2	Sea water	1.03
Copper	8.8	Kerosene	.8	Silver	10.5
Cork	0.2	Lead	11.4	Tin	7.3
Ebony	1.2	Mercury	13.6	Water	1.0
Gasoline	.6	Oak wood	0.8	Zinc	7.1

CHAPTER XII

CLIMATIC INFLUENCES OF BODIES OF WATER

157. Questions for Discussion. 1. Why does a deep river not freeze to the bottom of the water? 2. Why does sprinkling the streets lower the temperature of the air? 3. If a bathtub contains hot water, and an equal amount of cold water is turned into one end of the tub from the faucet, will the temperature of the water soon be the same in all parts of the tub? 4. Why is it possible to raise peaches in Michigan, while in Illinois the peach crop is very uncertain and the trees are sometimes killed by the cold? 5. Why do the ranchmen of northern Texas often lose stock from exposure to cold, although the general average of winter temperature is not low? Why would this loss be unlikely to occur if all winter winds were from the southeast? 6. What are some of the causes of the popularity of lakes and ocean shores as summer resorts? 7. How can you account for the fact that there are often breezes from water to land in daytime and in the opposite direction at night, although there may be no general wind disturbances over large areas at the time? 8. Why may one shore of a lake be much better for fruit growing than another? 9. Why do the Bermuda Islands, in the latitude of Savannah, have a more equable climate than Savannah?

158. Water and temperature. Those who have gone bathing in river, lake, or ocean have noticed that the water is usually cooler than the surrounding air. The common practice of spending the summer season near lakes or ocean is not primarily for the sake of using the body of water, but because the surrounding air is likely to be cooler than the air many miles away from such bodies of water. The larger the body of water, the greater the influence on temperature. Since three fourths of the earth's surface is covered by water, it is clear that any effect water exerts on temperature is extensive. It is easier to see the nature of this influence if we

use as illustration smaller bodies of water than the ocean, for instance, the lakes.

After we have secured some definite information regarding the influence of a lake upon the surrounding communities, we should be able to apply this information to the explanation of the effect which bodies of water have upon the lives

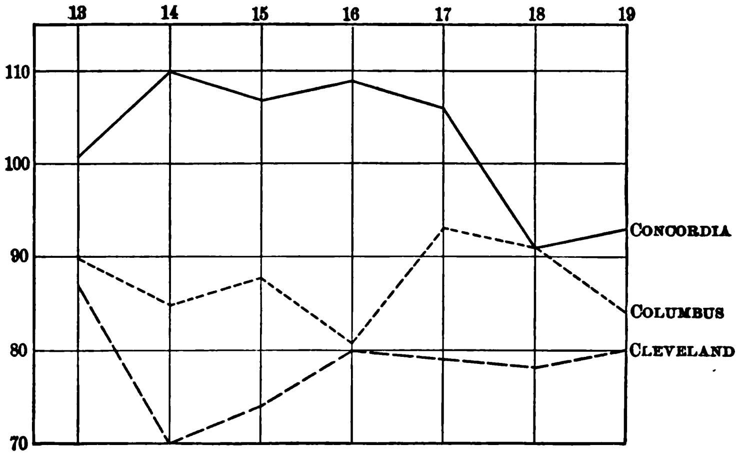


FIG. 72. Temperatures during a hot wave

The diagram shows the relative temperatures of Concordia (Kansas), Columbus (Ohio), and Cleveland (Ohio) from July 13 to July 19, 1913. Cleveland is on the shore of Lake Erie

and industries of men in various parts of the world. By studying figure 72 it will be seen that on July 14, 1913, Cleveland, Ohio, had a temperature of 70° F., while Concordia, Kansas, at a higher elevation, had a temperature of 110° F. The figure shows other interesting facts. During periods of warm weather the temperature at lakeside places is usually lower than at inland points in the surrounding country. On July 17, 1913, the United States Weather Bureau reported the highest temperatures for the day at Milwaukee, Chicago, Detroit, and Cleveland to be from 74° to 78° F., while at the same time the adjacent parts of the

Mississippi Valley were suffering from a hot wave and nine stations reported temperatures of 100° F. or higher. There were other days, however, on which the temperature of the cities named was as high as that of the neighboring places. Isolated instances such as those given do not prove anything. In order to secure a clear idea of the conditions, it is necessary to know the mean temperatures at the places compared.

The accompanying table gives the mean monthly temperatures from many years' observations, as ascertained by the United States Weather Bureau, for three cities located on the shores of Lake Michigan and in the adjacent country. The mean monthly temperatures are definitely lower during the summer months at the lake cities than at inland points in approximately the same latitude. There is foundation, therefore, for the belief that the shores of the lakes offer more comfortable summer temperatures than may be found at other places. The same conclusions would be reached if other lake cities were compared with places remote from the lakes.

MEAN MONTHLY TEMPERATURES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Madison . . .	16.9	18.7	30.4	45.6	57.6	67.3	72.0	69.8	62.3	50.0	35.1	22.8	45.8
Milwaukee . .	20.5	22.3	31.4	43.3	53.6	63.6	70.0	68.9	62.0	50.2	35.8	25.4	45.6
Grand Haven	24.6	23.8	31.5	43.8	54.4	64.1	68.8	67.3	61.2	50.1	37.9	29.2	46.4

159. Lake and sea breezes. Those who live near the shores of any large body of water are accustomed to attribute much of their freedom from great heat to the breeze (fig. 73). This breeze frequently blows on hot days and gives relief. Often the morning is quite warm, with rapid increase of heat as the sun gets higher in the heavens, until about ten o'clock, when a cool breeze begins to blow from the lake and the temperature becomes comfortable again. The breeze may

continue until about four o'clock in the afternoon or later. Its effect is most pronounced near the water, and it does not extend many miles inland. The same phenomena are observed on ocean shores.

160. Cause of the lake and sea breezes. To account for these breezes the causes for the movement of air need to be recalled (Chapter I). One cause is the difference in temperature. When air is expanded by heating, it becomes lighter; that is, a cubic foot of it weighs less, because the amount of air that occupied a cubic foot of space before

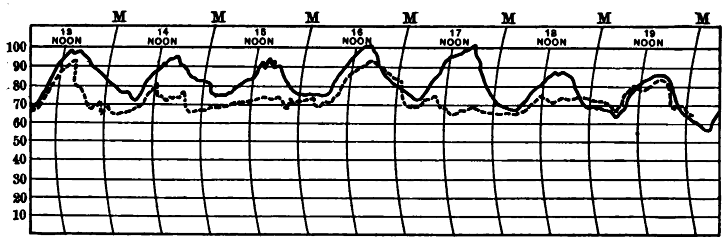


FIG. 73. Daily variations in temperature

Diagram showing the daily variations in two cities from July 13 to July 19, 1913. The solid line represents Peoria, and the broken line represents Chicago. Note the effect of Lake Michigan

it was heated has expanded. If next to the warm air there is a quantity of colder and heavier air, this colder air will tend to flow in under the warm air and lift it up. This is what happens in the vicinity of a stove or radiator, where the cool air is continually flowing toward the stove, where it is warmed and in turn displaced by the other cool air, thus making a continuous current.

The same thing occurs along a shore. In summer the land is much hotter than the water, at least while the sun is shining. Like the stove, the land heats the air which is over it until this air becomes so light that the heavier air above the water begins to flow out over the land, crowding the warm air upward (fig. 74). The air from the water becomes

heated as it flows across the land, and rises as it is displaced by more air from the lake. Thus there is a continuous flow of air across the shore line from water to land as long as the land is hotter than the water, excepting when local breezes are counteracted by stronger and more general movements of the air. The breeze gets well started about the middle of the forenoon, the time the land ordinarily becomes heated. During the night the land may be cooler than

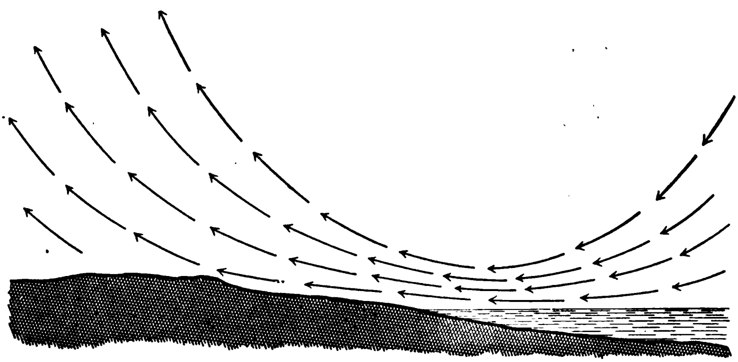


FIG. 74. Air movements from water to land

When the land is warmer than the water, cool and heavy air from the water flows over the land, pushing the lighter, warm air upward. Such movement of the air is known as a lake breeze or sea breeze

in the daytime; sometimes so much cooler than the water that the air flows from the land to the water, but this land breeze is much less noticeable than the water breeze.

161. Causes of unequal heating of land and water. The more rapid heating of the land is due, first, to the fact that it is not transparent. All the heat of the sun is received on the surface of the land, and the upper few inches are very rapidly heated, while the lower parts receive the heat slowly. Indeed, so slowly is heat transmitted to the deeper layers of the soil that at a depth of a comparatively few feet the temperature does not change either in summer or winter. On the other hand, the sun's rays penetrate into the water to a

considerable depth (fig. 75), the exact distance depending on the clearness of the water. If the water is clouded by sediment, the rays of the sun do not penetrate very far. A second reason is that since the sun's rays are reflected from the water more than from the land, much of the heat is reflected also and does not actually enter the water. A third reason lies in the fact that the water moves easily. Waves and currents mix the warm surface waters with the cool deeper layers, thus scattering the heat widely. For these reasons, although as much heat will be received upon a square foot of water as of land, no part of the water is heated so highly.

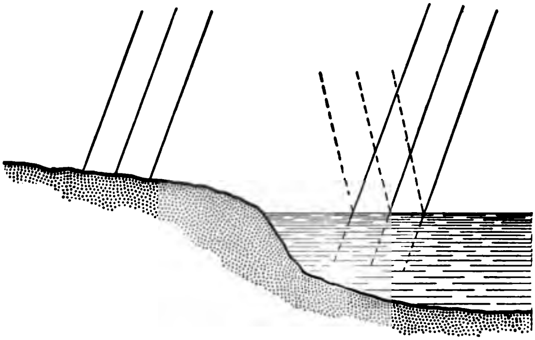


FIG. 75. Action of the sun's rays on land and water

When the sun's rays fall upon the surface of the land, they are mostly absorbed at the surface. The water reflects some of the light and heat, and the remainder may penetrate to considerable depths

The fourth and most important reason is found in the effect of a given amount of heat upon different substances. If a kettle of water and a flatiron are placed on the kitchen range at the same time, the iron will be heated more rapidly than the water. If a pound of iron and a pound of water are placed on the stove and exposed equally to the heating surface, it will be found after a short time that the iron is much hotter than the water. The same amount of heat has much less effect on the water than on the iron, so far as raising its temperature is concerned. The amount of heat which will warm a pound of iron 1° C. will warm a pound of water only 0.11 of 1° C.; that is, it takes over nine times as

much heat to produce a given temperature in the same weight of water. There are so many kinds of soil that if we were to use soil instead of iron for this experiment, the results would vary widely.

162. Cooling of land and water. The land cools more rapidly than the water. As it is necessary to put more heat into water than into land in order to raise its temperature a given amount, so the water gives off this larger amount of heat when it cools. Furthermore, as water cools it gives off its heat slowly, and since much of the heat is in the deeper

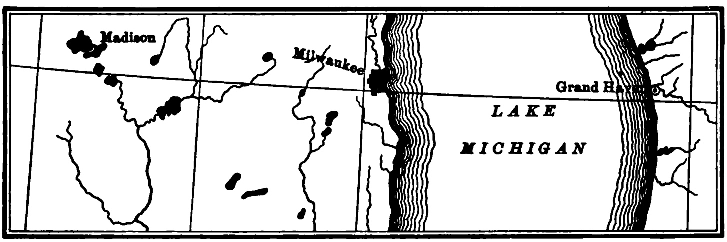


FIG. 76. Cities with different locations in the same latitude

parts of the water, it is not readily given off. We may therefore expect that any body of water will be cooler in summer than the neighboring land, at least during the daytime and while the sun is shining, and that breezes from water to land will be common. During the winter the water may remain much warmer than the land.

163. Extent of influence of water. Although the lake breezes are local, the temperature effect of the lakes is carried much farther inland. We need to study again the table of mean monthly temperatures in order to see what this effect is. Since the three points Grand Haven, Mich., Milwaukee, Wis., and Madison, Wis. (fig. 76) are in the same latitude and so located that one is close to the east shore of the lake, one near the west shore, and one remote from the lake, we shall have proper points for comparison.

In the summer months we find that the means are a little lower at Grand Haven than at Milwaukee, and highest of the three at Madison. In the case of these three towns, at least, it appears that the lake may bring about lower summer temperatures in its vicinity, particularly on the eastern shore. We cannot be sure of a general law by studying three cities

MINIMUM DAILY TEMPERATURE DURING A COLD WAVE IN 1913

DATE	CHICAGO	DUBUQUE	GRAND HAVEN	GRAND RAPIDS	MADISON	MIL-WAUKEE	ST. LOUIS	SIOUX CITY
Jan. 2	5	– 5	9	9	– 8	– 4	16	– 13
3	5	– 6	9	9	– 8	– 4	9	– 9
4	– 6	– 9	2	2	– 13	– 11	7	– 13
5	– 10	– 19	– 1	– 2	– 23	– 18	– 1	– 20
6	– 11	– 19	0	– 1	– 24	– 18	– 9	– 20
7	– 16	– 22	– 3	– 5	– 24	– 18	– 14	– 26
8	– 3	– 3	– 2	– 2	– 7	– 5	0	– 7
9	– 4	– 10	3	2	– 14	– 10	10	– 5
10	– 6	– 15	2	0	– 15	– 13	4	– 7
11	– 3	– 19	– 3	1	– 19	– 14	– 2	– 26
12	– 3	– 26	– 14	– 9	– 25	– 14	– 9	– 35
13	– 1	– 18	– 2	– 1	– 20	– 9	– 8	– 8
14	4	– 2	10	9	– 2	0	12	– 9
15	– 2	– 10	5	3	– 10	– 5	– 4	– 17
16	– 2	– 12	5	2	– 11	– 5	0	1

only, but from many such studies it can be stated that a similar state of affairs is found to exist in all places in this region.

If it is the winter temperatures to which we give our attention, we find that again the west shore occupies an intermediate position, the east shore is warmer, and the country away from the lake much colder. In the table given above there is given the record of the lowest point reached by the thermometer on each of several days during a severe cold wave in the first part of January, 1913. The illustration (fig. 77) represents in diagrammatic form the conditions in three cities. It will be noticed that the cold is less severe on the east shore than

on the west, and less severe on either shore than at places far distant from the lake but in the same latitude.

164. Causes of difference between east and west shores. It will be recalled that in connection with the study of the wind movements of the earth we found that the United States is in a belt of prevailing westerly winds. We have

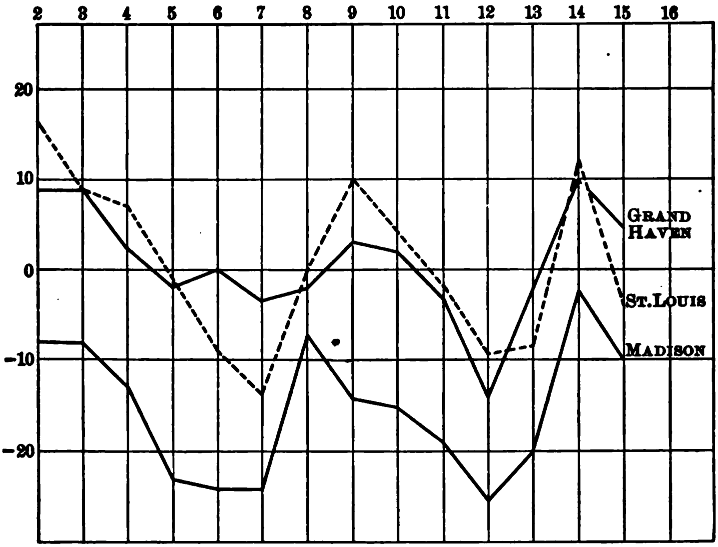


FIG. 77. Temperatures during a cold wave

The diagram represents the variation in temperatures between three cities on the dates January 2 to January 15, 1913. Grand Haven is in the latitude of Madison, but its temperature is like that of St. Louis

winds from all points of the compass, but our winds much more frequently blow from a point west of a north-and-south line than from a point east and west of such a line. They are usually southwest, west, or northwest. It follows from this that on most days of the year the air over the country from the east of the lake has come across the lake. On the west side the influence of the lake is very slight excepting on a few days when the wind is from an easterly

direction or when the west wind is so light that a lake breeze develops. The effect of the lake is particularly important in case of a cold wave, for our coldest winds are from the northwest.

The influence of lakes tends to reduce the extremes of temperature. Places near lakes have on the average cooler summers and warmer winters than they would otherwise have. This effect is great enough to be of some importance on the west shores of the lakes, but it is of much greater importance on the east shores.

Similar conditions will be found in the vicinity of any large body of water in a temperate latitude. In tropical countries, where there is no cold season and the winds are easterly, conditions are somewhat different, but the same principles apply. The western coast of each continent is warmer than the eastern coast in the same latitude.

165. Some effects of lake climate. The coolness of the summer months attracts thousands of people from the hotter parts of the country to the shores of lakes and oceans. Thousands of summer residences have been built and whole summer cities have grown up along shores which are sometimes so barren that, were it not for the climate, scarcely anyone would live there. During the winter these settlements are often almost wholly deserted.

Back from the shore of Lake Michigan and for many miles inland the climate is so modified that it is possible in the lower peninsula of Michigan to grow fruits which cannot be grown with success away from the lake, excepting some hundreds of miles farther south. For instance, peaches are grown largely on the east side of Lake Michigan, but they do not succeed well on the west side; indeed, it is necessary to go as far south as southern Illinois and middle Missouri to find an equally favorable climate.

The influence of the lake hinders the occurrence of early frosts in autumn and delays the return of warm weather in

spring. The peach trees are thus prevented from starting growth during an occasional warm spell in spring and are often preserved from the dangers of late frosts.

Other regions are similarly favored by the influence of the Lakes, as is illustrated by the fruit-growing country lying east and southeast of Lake Erie, and the great Canadian peninsula extending down between Lakes Huron, Erie, and Ontario. The mildness of the climate of the Pacific coast even as far north as Alaska is due to the influence of the ocean, assisted by certain ocean currents, and many other similar illustrations might be cited.

CHAPTER XIII

WATER AND COMMERCE

166. Questions for Discussion. 1. What large cities of the United States are located on large bodies of water and at the mouths of large streams? Why are they so located? 2. Why is it that early settlements of the United States began on or near bodies of water? 3. Who were the first settlers in your state, and by what routes did they enter it? 4. What are the leading ship canals of the United States? 5. In what ways has the transportation of your state been influenced by lakes, oceans, or rivers? 6. Is water transportation as important or more important in your state now than it was a century ago? 7. Are there towns or communities in your state wholly dependent upon water transportation? 8. What is the purpose of lighthouses? of life buoys? 9. Why does the United States government and not the state government take charge of lighthouse stations? 10. Of what advantage or disadvantage would it be to Mississippi and Louisiana to have the Chicago Drainage Canal and the stream into which it empties made large enough and deep enough to permit large steamers to pass through them?

167. Commercial importance of waterways. From the time of most primitive civilization men have constantly been using water craft as means of transportation. Much of man's inventive genius has related to improvement of devices for travel by water. Throughout the ages success or failure in contests between nations has been affected largely by the relative advancement of the contending nations in knowledge of sea craft. In the greatest of wars, involving all the leading nations, the race-old question of control of the seas is still a highly important one.

Though commerce and other ocean travel between nations is great, the industrial, economic, and social uses of inland waterways are of even more direct significance. Since ocean

Fig. 78. Interior navigation

It is not easy to define navigability of rivers, since there is variation in the depth of the water and in the kinds of boats used. Assuming three feet as the minimum depth of navigability, the rivers of the United States provide over 14,000 miles of navigation measured in straight lines, and much more if the real stream courses are measured

travel is like inland water travel, only over greater distances, usually with larger vessels, and between different peoples instead of between different parts of the same people, a study of inland waterways will give an insight into both. In bulk of business inland waterways are very important (fig. 78). The traffic through Sault Sainte Marie Canal, connecting Lakes Superior and Huron, is about four times as great as that through Suez Canal, even though the Sault Canal is closed by ice about five months of the year. A yet greater amount of traffic passes through the Detroit River, and this stream is one of the busiest waterways in the world.

168. Water transportation on the Great Lakes. Much of the commerce of Chicago,[1] the greatest railroad center in the country, is carried by water, owing to certain advantages of water transportation. In the first place, it is often cheaper, since it costs a good deal to build railways. There is less expense for repairs of boats, harbors, and docks than of roadbed, track, and rolling stock.

Water transportation is usually slower than transportation by rail. In the shipment of such slow-moving water freight as coal or lumber it is necessary to start the freight so as to have plenty of time. Heavy and bulky articles, such as coal, iron ore, stone, lumber, and grain, are commonly transported by lake or river route where this is possible. One of the most important phases of the use of the Lakes to-day is the transportation of iron from the mines near the west end of Lake Superior and near Green Bay to the iron and steel plants on the shores of Lakes Michigan and Erie. The great furnaces of South Chicago, Indiana Harbor, and Gary at the south end of Lake Michigan are supplied by lines of steamers which run directly from the ore docks on Lake Superior and

[1] In this chapter and those that follow, conditions about the Great Lakes are frequently cited as illustrations. Those of other regions where the records have been kept for a considerable period will serve equally well, and such records should be secured as a means of demonstrating the local importance of the facts under discussion.

on Green Bay to the private wharves of the steel plants. These boats are built for this service and carry no other freight. Other lines of boats run through Lakes Huron, St. Clair, and Erie to Cleveland and other ports on Lake Erie, where the iron ore is either smelted or shipped to inland points, such as Pittsburgh. Other important articles of commerce on the Great Lakes are coal, grain, and lumber, which are shipped to many thriving cities located on these lakes.

Many of the industries of the Lake ports depend largely upon the materials which are brought by water, and many citizens are there because of the opportunities afforded them by the industries which depend wholly or in part upon this commerce. It is true that these cities might be able to exist without the Lakes, as other cities do, but they doubtless would be different in many respects, and it is quite possible that they might not have been established or that they might be at different places and engaged in different activities.

169. Origin of lake cities: Chicago as a type. The first white settlers and travelers in the region of the Great Lakes were the French. They came into the country by way of the St. Lawrence River and early discovered the Great Lakes. As they pushed their explorations farther west they adopted the Indian canoe as their chief means of travel, and the most important roads for them, as for the Indians, were the rivers and lakes (fig. 79). When they had discovered the Mississippi River and formed settlements and military posts upon it, their route from Canada to the Mississippi was through the lakes to the shore of Lake Michigan, then up some stream emptying into the lake, and across the country to another river down which they might float to the Mississippi. There were several such routes in use. One of them crossed the present site of Chicago. When traveling by this route the *voyageur* paddled his canoe to a point near the south end of the lake, where he entered the Chicago River. He followed the south branch of this stream to a point

near the western limits of the present city. A short carry, or portage, brought him to the Des Plaines River. Indeed, in times of flood it was often possible to travel almost the entire distance by canoe. Once in the Des Plaines River, he might easily pass with the current down to the Illinois River, to the Mississippi, and even to the Gulf of Mexico. The short portage at Chicago and the importance of the French posts on the Illinois River made this a favorite route. When sailing ships began to be used on the Lakes, it was natural that the traveler should wish to go as far as possible on the ship and as short a distance as possible in the canoe. Ships brought travelers and goods to the south end of the lake, and the mouth of the river afforded a safe harbor for the vessels and a landing place for the goods. The French lost possession of the country, but the routes of travel and commerce did not change.

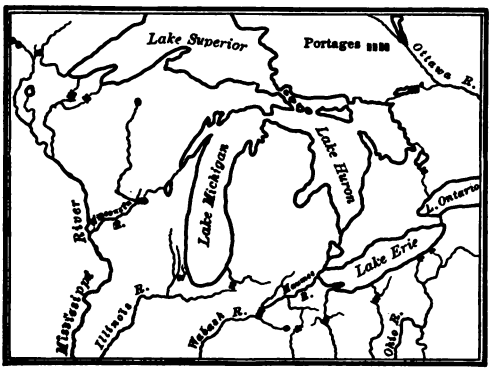


FIG. 79. Early routes of travel

The map shows the headwaters of rivers and the lakes which were important in determining the courses taken by early hunters and settlers. Portages shown by ıııı

When travel and commerce had increased, people began to settle at the point where the ships came to unload. A fort was built to protect the settlement and to defend the route of travel. This was known as Fort Dearborn, and its location was in the center of the present city of Chicago.

170. Extension and improvement of waterways. As population increased, the need for good transportation facilities increased also. Steamboats abounded on the larger rivers,

and sailing vessels on the Great Lakes, but there was no route by which freight vessels could pass between the Lakes and the greater river systems. To meet these needs a number of canals were dug. Erie Canal is the most widely known, but there are others in Pennsylvania, Maryland, New Jersey, Ohio, Illinois, and other states.

One of the canals was completed in 1848 and connects Lake Michigan with the rivers of the Mississippi system. The conditions which made it easy for the French and Indians to get their canoes from Lake Michigan to the Illinois River by way of the Chicago and Des Plaines rivers also made it easy to dig a canal, known as the Illinois and Michigan Canal, along the same line, for the divide between the two rivers is at one place not more than fifteen feet higher than the lake. The canal begins only a few miles from the old French and Indian portage and extends along the valley of the Des Plaines and Illinois rivers to La Salle, Illinois, where it enters the Illinois River. Thus the route used by the Indians for many centuries became the route of modern commerce, and the fort became a great city.

171. Railroads. Soon railroads were built in the same region, and then the canal became less important, but two of the railroads were built along the same old route of early Indian travel. In the valley of the Des Plaines River, leading southwest, there are the river, the old canal, two railroads, a wagon road, a trolley line, and the sanitary-drainage canal.

At the end of the lake was the only harbor in this vicinity where freight might be transferred between train and ship. The lake extends so far south that railways built westward from the larger cities of the East toward the rich prairies of the West found their shortest route close to the end of the lake. Thus the settlement on the main line of pioneer travel came to be on the main line of railway travel.

Elsewhere upon the shores of lakes, rivers, and ocean the towns which were originally centers of commerce by water

have become railway centers also. In many cases the railways have followed the routes which were earlier used by water-borne commerce. Thus the New York Central Railway parallels the Hudson River, Erie Canal, and Lake Erie, and two railways follow the route of the Illinois and Michigan Canal.

172. Harbors, lights, buoys, and life-saving stations. A good harbor is a necessity for any city which carries on commerce by water. There must be some place where vessels may lie in quiet water while unloading or taking on cargo. Harbors need more or less constant dredging. They need properly constructed breakwaters to check the force of the waves and produce a fairly quiet area behind them in which vessels can lie in security. Since the harbor is open to all vessels, it is the business of the government to make these improvements.

Lighthouses are placed at the harbor entrances and at other places to guide the master of a vessel safely into the harbor or to warn him of danger. Important lighthouses are equipped with foghorns, which are sounded at intervals of a number of seconds during rainy or foggy weather, when the lighthouse may not be visible. Obstructions, shallow places, and other dangers are commonly marked by buoys of different shapes and colors.

Life-saving stations are maintained at many places. Each station is in charge of a crew of trained and experienced men and is equipped with boats and other special apparatus for the saving of life in case of wrecks or other accidents. It is better, however, to prevent wrecks than to save life after a wreck, and one of the measures taken for this purpose consists in maintaining storm-signal stations, which are frequently connected with the life-saving station.

More has been said of Chicago than of other ports, since it is the largest city on the Lakes and the port closest to the heart of the country. Other lake and ocean ports, if carefully studied, will show interesting facts of a similar nature.

CHAPTER XIV

WATER SUPPLY AND SEWAGE DISPOSAL

173. Questions for Discussion. 1. What are the principal sources of pollution of the streams in your community? 2. Is pollution of streams caused by necessity or carelessness? 3. Why is the water of a mountain lake commonly supposed to be free from disease-producing bacteria? Is such water always safe? 4. What advantages come to a city as a whole from providing good water and from proper disposition of sewage? 5. When a sewer system has been provided, and certain house owners fail to connect their premises with it, is this a matter of any concern to their neighbors? Is it a matter of concern to other citizens who live in distant parts of the city? 6. If waste matter is not properly disposed of on farm premises, may this concern residents of the neighborhood and of cities and towns close by? 7. Try to secure the records of a case in your community or state where typhoid fever has been spread by the use of impure water or milk. What was the evidence that water or milk was the source of infection? What was done to prevent further spread of the disease? 8. What is the explanation of the fact that over 70 per cent of farm wells in Illinois less than 25 feet deep were impure, while of farm wells 50 to 100 feet deep somewhat over 10 per cent were impure? 9. Secure from your state health department any available information regarding efforts to insure pure water for the state and what still needs to be done.

174. Sources of water supply. If we are accustomed to drinking as much water as good health requires and are deprived of it for a few hours, we soon realize how very dependent we are upon it. Its use in cooking and cleansing is also highly important. One of the most difficult problems confronting people both in city and country is to secure an adequate and desirable quality of water.

In the country or small villages dependence is placed upon wells or occasionally upon springs. In a city this source is

not practicable. It would be extremely difficult to secure from wells a supply sufficient for a large city, and, furthermore, the soil in cities becomes so filled with various waste materials that the waters from surface wells would hardly be suitable for use. The other available sources of supply in most cases are lakes or rivers, both of which need much study to make certain that they are always safe.

175. Importance of pure water. The importance of pure water lies very largely in its relation to disease. We have learned that many kinds of bacteria are commonly found in water, and that no water is entirely free from them unless it has been sterilized. If these bacteria are of the kinds that produce disease, serious results may follow when the water is used for drinking and for domestic purposes.

The most important disease bacterium found in water is the typhoid bacillus (Chap. IX). For that reason the death rate from typhoid fever is often taken as a sort of index to the condition of the water supply. There is given here a graphic representation of the typhoid death rates in a number of cities (fig. 80). You will be able to draw your own conclusions as to the safety of the different sources of supply.

At one time Chicago had a typhoid death rate of 173 per 100,000 population, and at that time this was the highest death rate from typhoid in the civilized world. The rate was only 13.7 per 100,000 in 1910, 7.6 in 1912, and 5.1 in 1916. The changes in water supply and sewage disposal, together with other modern methods of health control, have been important factors in securing this reduction.

176. Impurities in water. Some of the many kinds of impurities found in water are highly objectionable, while others are of very little consequence. These substances may be grouped in three classes: dissolved substances, sediments, and bacteria.

Certain dissolved substances in water produce what is commonly known as hard water. Hard water is an annoyance

in many ways, but it is not known to have any serious effect on health. The chief annoyance is the curd that forms in it when soap is used, and it is also wasteful of soap. One of the commonest substances is lime, which is really dissolved limestone. Lime is deposited in a teakettle when hard water is boiled in it, and in this way the water is made soft. Some other substances in hard water cause more serious annoyance because they can only be removed by the addition of

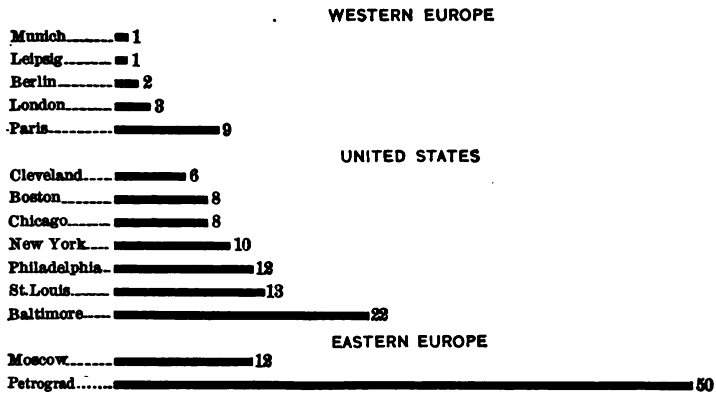


Fig. 80. Death rate from typhoid fever

The figures show the number of deaths per hundred thousand population, based upon data for 1912. The dark line indicates the proportionate number of deaths in each city

chemicals. Borax, sal soda, ammonia, and lye are commonly used for this purpose in order to save soap.

Sediments, or solid particles, of various sorts are present in all natural waters. We usually speak of them as mud, clay, sand, etc. If the water is allowed to stand for some time the sediment tends to settle to the bottom. The sediments present in lake waters have been brought in by rivers or stirred up by waves along the shore, there being little sediment in the water a few miles from land; but in rivers they remain in suspension for a longer time. Sediments make the water less inviting, but may not in themselves be dangerous.

The third kind of material — bacteria — is in reality a sort of sediment, but bacteria are of such importance that they will be discussed separately. Indeed, the principal importance of other sediments lies in the fact that bacteria are likely to be associated with them. The mud along the shore usually has a great deal of refuse mixed with it. There are great numbers of bacteria living in this mud, and if it is stirred up by the waves and mixed with water, the bacteria are likely to be distributed as widely as the mud is. Water which is muddy is often dangerous and always open to suspicion.

177. Sources of bacteria in lakes and rivers. Natural waters are never wholly free from bacteria. Every rain washes them into the streams. The most important source of bacteria in many of our streams is the sewage of the cities on their banks. The bacteria from this source are particularly objectionable because the sewage includes human wastes and therefore commonly contains the germs of such infectious diseases as are present in the community. As the water flows down the river many of the bacteria settle to the bottom along with other sediments or are killed by exposure to air and sunlight. Excepting near the source, very few rivers in their natural condition are suitable for domestic use.

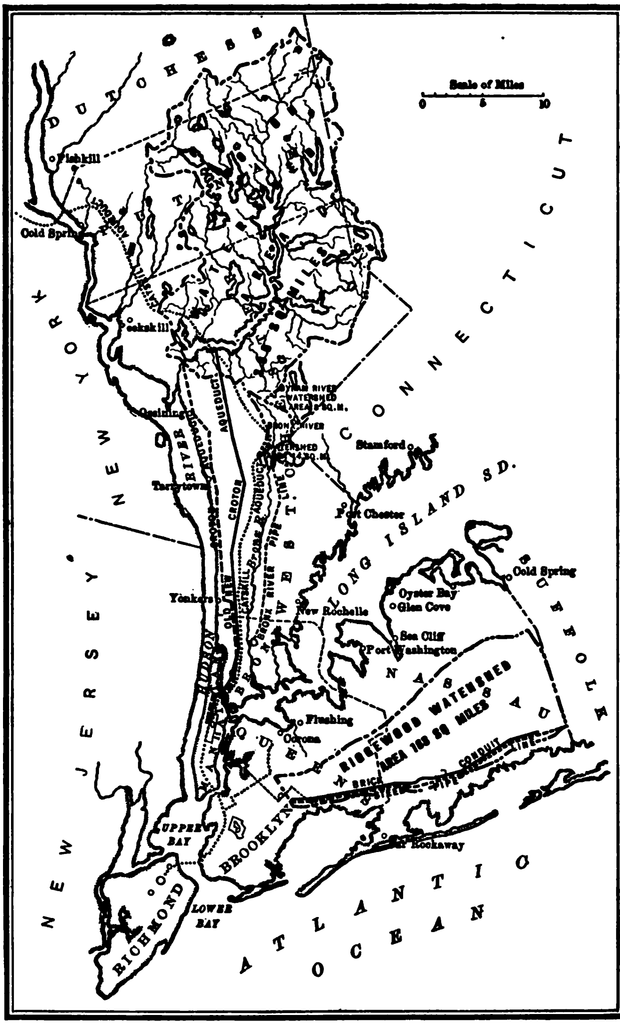
The larger lakes are fed by many rivers and therefore receive large numbers of bacteria from them. Contamination is increased by refuse dumped alongshore and by the sewage of adjoining cities. The principal sources of contamination of lake waters are located near shore. The waters of the center of the lakes are polluted only as bacteria and other sediments are carried out into the lake by currents. The movements of lake water are so slow that bacteria and other sediments usually settle to the bottom before they have traveled many miles from land. For this reason the water in the central part of large lakes is usually of excellent quality. As cities increase in size, however, the zone of pollution alongshore extends farther into the lake.

178. Methods of securing pure water. The cities on large lakes have ordinarily taken their water supplies from the lakes. They have sought to secure pure water by constructing tunnels in the lake bottoms which make it possible to secure water from points at a distance of from one to six miles from shore. Even this distance is not great enough to guarantee pure water in all cases, and filtering or other means of purification is desirable.

Some cities may secure water from mountain streams which flow from valleys that are almost or quite uninhabited. The water of such streams is usually of excellent quality and, if protected from contamination by the inhabitants, will carry almost no disease-producing bacteria. Since the lands in the mountain regions are commonly of comparatively little value for agricultural purposes, it has been possible for certain American cities to acquire control of the entire drainage areas of the streams which supply them with water (fig. 81). With proper care these regions may be preserved from contamination and the purity of the water insured. The United States Forest Service is coöperating with certain cities in preserving from contamination those parts of the reserves which drain into the streams from which these cities derive their water supply.

For many cities the only available source of water supply is a river or lake which has become contaminated. In some cases this water is pumped into the mains without any attempt to avoid contamination. The result is that the health of the people suffers and the death rate is abnormally high (fig. 82). The citizen of such a city can protect himself from the danger of polluted water only by boiling the supply that he uses for drinking and domestic purposes.

All cities that are properly organized and governed guard the health of their citizens by proper attention to the quality of their water supply. If this must be taken from a contaminated source, it can be purified by any one of several methods.



. Fig. 81. The water supply of New York City

The water is taken through a large aqueduct from the Catskill Mountains to the city

Many modern cities have installed filtering plants in which the bacteria are removed from the water by passing it through beds of sand. Other cities kill the bacteria by the action of certain chemicals which, when added to the water in proper proportions, are fatal to the bacteria but are not harmful to people.

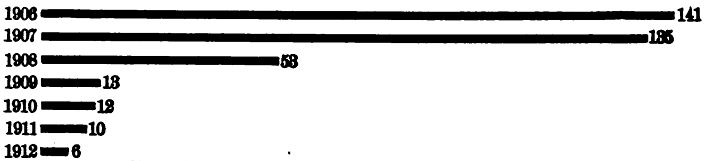


Fig. 82. Effect of purifying the water supply

Diagram showing the typhoid death rate per hundred thousand population in Pittsburgh, Pa., during a term of years. A filtration plant was installed in 1908

Storage reservoirs in the form of natural or artificial lakes are common accessories of water systems. Usually the principal purpose of a reservoir is to accumulate a supply of water when it is plentiful, in order that there may be no scarcity during a dry season or in case of unusual demands

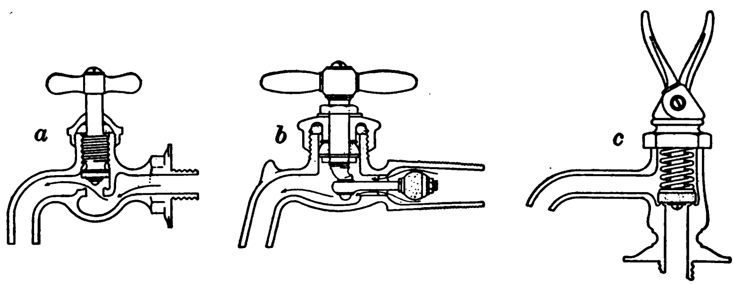


Fig. 83. Types of water faucets

The faucet *a* must be closed by hand; *b* is self-closing by water pressure; *c* is self-closing by pressure of a wire spring

of any kind. At the same time the quiet waters of the reservoir offer a favorable place for the finer sediments, including bacteria, to settle to the bottom. The water is thus purified while it is being held in storage, and in some water systems this is the most important means of purification used.

179. Proper handling of water in the house. In modern well-built houses much attention is given to proper plumbing to insure the delivery of water to the parts of the house where it is needed and to avoid contamination. Small pipes are attached to the large pipes or mains underground in the street. The small pipe enters the basement of the house, and branches then lead to the parts of the house where water is needed. Owing to the high pressure produced in the mains by means of the pumping station or the height

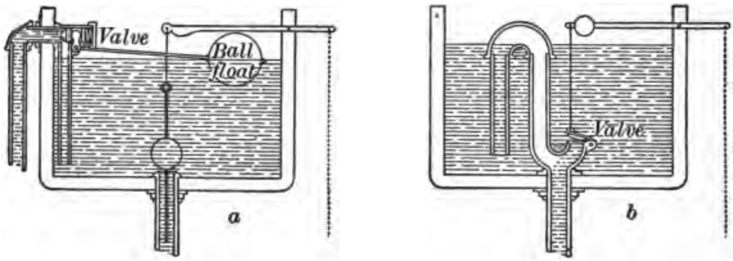


FIG. 84. Types of flush tanks

In *a* the valve for the entrance of the water is closed when the water in the tank has floated the ball to the level shown. The outlet pipe at the bottom is closed by a sphere of metal. In the tank at *b* the entrance pipe is not shown. The outlet pipe is opened by a ball valve in *a*, and by a hinge valve in *b*

of the reservoir, the water may be drawn off at the faucets. The ordinary user of water has little to do with the system except to use the faucets. Three types of faucets (fig. 83) illustrate those most commonly used. Whenever a larger quantity of water is needed in a short time, as for flushing a water closet, a tank is used in such a way as to be filled through a faucet which is opened and closed automatically by a floating hollow ball or by a siphon valve. The tank (fig. 84) is emptied by pulling a chain or pressing a lever which opens the tank directly or starts the siphon. When the tank is empty the water flows in at the faucet until the hollow ball has risen to a point where the metal arm to which the ball is attached has closed the faucet.

The waste water from the house is collected through sinks, wash basins, bathtubs, laundry tubs, water closets, refrigerator drains, and the overflow from tubs, basins, etc. Each of these fixtures (fig. 85) is connected with the drain

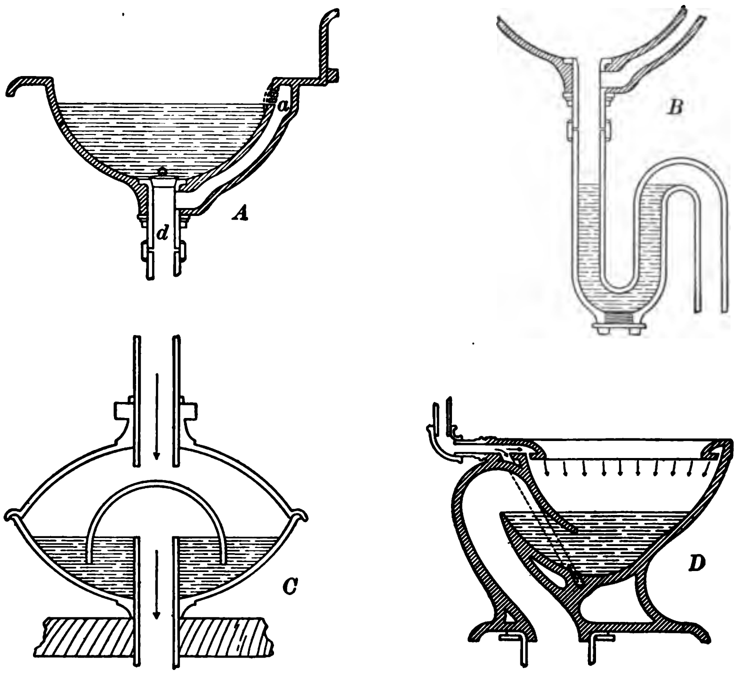


Fig. 85. Types of water basins and traps

***A*, wash basin with safety overflow devices: excess water flows through *a* and out at *d*; *B*, trap below wash basin; *C*, trap below an ice refrigerator; *D*, overflow pipe constructed with entrance pipe**

pipes which carry the house wastes into the sewer. These connections should always be made by means of a trap to prevent gases and odors from entering the house. Various kinds of traps are used, but in each some water is caused to remain in the trap in such a way as to seal the opening completely, preventing passage of air currents.

180. Sewage disposal. Much of the waste is in solid form (garbage, ashes, etc.), and the proper disposal of this is important and difficult. We shall here concern ourselves only with that which is washed away in running water — the sewage. That there will be a great volume of this is evident, for most of the water that is pumped into the city eventually finds its way into the sewers. In addition most of the water from rains is turned into the sewers by the catch basins in the gutters.

The simplest way to get rid of waste water and sewage is to allow it to run off over the surface of the ground in gutters. This objectionable practice is common in oriental cities, and even some American cities still permit such a system. Indeed, open sewers may be found in neglected parts of many of our cities. An open sewer is always a source of danger and should be a matter of concern to every citizen.

The modern and sanitary way to construct sewers is to place them underground. There is usually a sewer in every street, and every house should be connected with it. The smaller sewers unite with larger ones, which finally discharge the sewage into a lake, river, or ocean, or, what is far better, into a modern sewage-reducing plant.

181. A sanitary canal. Although Chicago is in the basin of the St. Lawrence River, at the present time its sewage flows into the Gulf of Mexico. The way this was accomplished forms an interesting illustration of what a modern city will do to dispose of its sewage so as not to spoil its water supply. The route which afforded an easy passage for the Indians, the French (Chapter XIII), and the builders of the Illinois and Michigan Canal and of wagon roads and railroads has proved equally suitable for the route of the canal built to carry away the sewage of Chicago.

The building of this canal was possible because, as stated in the preceding chapter, no part of the old portage was more than fifteen feet above the level of the water of the lake. The

current now flows from the lake into the mouth of the river and up the South Branch, where it enters a new canal, known as the sanitary or drainage canal, thus reversing the recent course of the river. In this way part of the water of Lake Michigan, the normal outlet of which is through the St. Lawrence system, now flows into the Gulf of Mexico and carries with it the sewage of Chicago. In prehistoric times Lake Michigan stood at a higher level, and its waters emptied into the Mississippi system along the route now followed by the drainage canal.

The construction of the sanitary canal cost more than $56,000,000. The city health department reports that during the ten years before the opening of the canal, in 1900, the average annual death rate from typhoid fever was 66.8 per 100,000, but in the ten years following, the rate was only 22.3. It is calculated that this represents a saving of 8814 lives. Each life has a money value, dependent upon earning capacity. The health department has calculated that the actual money value of these lives to the community was nearly $53,000,000. In other words, the canal almost paid for itself in the first ten years. It will always pay any city to secure pure water at any necessary cost.

182. Sewage treatment. The common method of disposing of sewage and other wastes by discharging them into streams, lakes, or ocean is obviously highly objectionable, and the nuisance tends to increase with the growth of population. At many places it has become necessary to treat the sewage in a manner that will remove its objectionable qualities before allowing it to enter the watercourses. This is usually accomplished by bacterial action and filtration. Chemical treatment may be used, also, to destroy bacteria. Sometimes the sewage is used to irrigate land.

183. Rural water supplies. The water supply of farms and villages does not usually receive so much attention as that of cities. Most of the inhabitants of a city secure their

water from the public waterworks, and any fault in the system affects the whole city, thereby attracting attention. In rural districts, on the contrary, each home has its own independent source of water, commonly a well, and contamination of any one well does not usually affect so many people. It is quite possible, however, that many wells may be in a polluted condition at the same time, and the average character of the water in a rural community may be very bad. Indeed, typhoid and other water-borne diseases are often more prevalent in the country than in the city. City health officers have learned to expect an increase in the

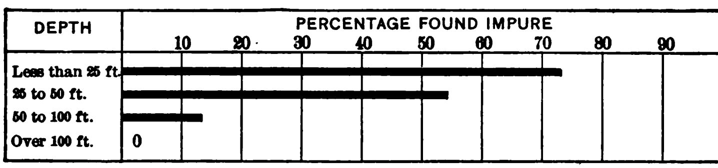


FIG. 86. Purity of farm wells

Results of the examination of farm wells in Illinois. Deep wells are more frequently pure. After data by Bartow

number of cases of typhoid in the city at the time of year when people return to the city from vacations in the country.

The water in an ordinary well comes from the rain water which falls upon the ground within a few hundred feet of the well and percolates through the soil until it reaches the well. Such water has usually been contaminated more or less at the surface of the earth with the various bacteria which may be present upon the surface or in the upper layers of soil (fig. 86). As the water percolates through the soil many of these bacteria are removed by the filtering action of the soil. If the bacteria are not too numerous, and if the soil is sufficiently compact and the distance the water travels through it is great enough, practically all the bacteria may be removed. On the other hand, if the well is located near a compost heap, cesspool, pigpen, or other

source of pollution, it is almost certain that the water in the well will be contaminated. If the ground slopes toward the well, this will favor contamination. It is very desirable, therefore, that a well be located far from all possible sources of contamination, that the ground slope away from it in all directions, and that it be tightly curbed and covered.

In many communities water is secured from wells frequently several hundred feet in depth. The water which enters a well from the deeper layers of the earth's crust has, of course, percolated a long distance through soil and rock and is very nearly free from bacteria, but such wells must be carefully guarded against the entrance of surface water. The lining of the well should be water-tight, and the surface waters carefully drained away from the vicinity of the well. A deep well protected so that surface water cannot enter is one of the most reliable sources of pure water. What has been said above regarding wells applies also to springs. Whatever the source of water for the rural home, it may be piped through the house in a manner similar to the city supply. Continuous pressure at the faucet may be obtained by pumping the water into a high tank placed either outside of the house or in the attic, or by an air-compression tank (fig. 87).

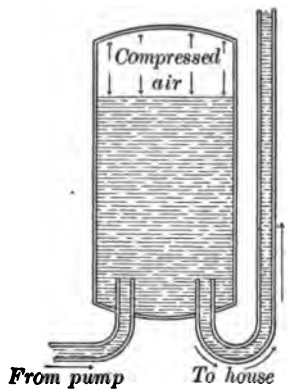


FIG. 87. Compression tank for rural water supply

Water may be held in the tank under pressure of the air by means of a valve in the pipe from the pump, and when the house faucets are opened the compressed air forces water through the faucets

184. Disposal of wastes in rural districts. In many rural districts the disposal of wastes is not given the attention that its importance demands. Too often manure heaps are allowed to become breeding places for flies, human wastes accumulate

in cesspools where they are accessible to flies as well as sources of contamination to wells, and the barns and outbuildings are in a condition that is a continual menace to health. It is obviously impracticable to construct sewage-disposal works which will serve an entire rural district as a city is served by its sewer system. It is, however, entirely practicable for each country residence to have its own individual plant for this purpose as well as for the supply of water. The main waste pipe of the house should empty into a cesspool which should be so located and constructed as to prevent contamination of water supply, diffusion of gases, or access of flies.

PART III. WORK, ENERGY, AND ELECTRICITY

CHAPTER XV

COMMON TYPES OF WORK

185. Questions for Discussion. 1. When a mountain stream wears away the stone and soil and carries them to a valley where they are deposited, is work being done? May work be considered as constructive or destructive, wasteful or useful? 2. Why is it desirable, in using any kind of machine, to decrease the amount of friction? Why do we oil a bicycle, automobile, sewing machine, or farm wagon? Can there ever be a truly automatic machine? 3. Why is there less friction in a machine with roller or ball bearings than in one with bearings of the usual type? 4. How does a set of pulleys enable a man to accomplish work which he could not accomplish unaided? 5. If a rope is arranged to run from a weight on the ground through a pulley attached to an elevated beam and down to your hand, will less force be needed to raise the weight than if no pulley were used? 6. Why is one's finger more likely to be crushed in a door if caught at the hinges than if caught at the latch? 7. When a long ladder is being raised, why must the lower end be braced against some heavy object? 8. How and when is water power used in getting the timber from the higher hilly or mountainous regions to the more level plains or to sea level?

186. About work in general. A great deal of the work of running water is of no immediate benefit to man. The great waterfalls of the earth may continue for many centuries without producing any noticeable change in the desirableness of the surrounding region as a place of human residence. To be sure, the gorge of Niagara may in time be extended so far upstream that it will reach and partly drain Lake Erie, but that event is far in the future. As a sublime spectacle the Niagara Falls may be of very great value, but as a worker

they have been relatively unimportant because their work has not been of a useful kind (fig. 88).

Of late years men have taken part of the water from the river above the Falls and caused it to flow through turbine water wheels on its way to the lower level in the gorge. This part of the water therefore turns the wheels and the dynamos

FIG. 88. Work done by Niagara Falls

At Niagara the river falls into the head of a narrow, steep-walled gorge. The gorge has been made by the river

connected with them instead of wearing away the rock of the Falls. Thus the Falls have been harnessed and compelled to do useful work. The beauty and impressiveness of Niagara Falls are so great that the Falls are probably worth more to us in their natural state than the energy we could derive from them would be worth, but there are many other places where water power can be produced without destroying great scenic beauty. It is necessary to take advantage

of water power and of other sources of energy in order to accomplish the needful work of the world. Buildings must be constructed, trains moved across the country, steamships driven across the ocean. Land must be plowed, crops planted, ditches dug, the floors scrubbed, the lawns mowed. Work must be done every day in every inhabited part of the world. If the land were not plowed and planted and the crops harvested, there would be little for us to eat. If the trains and ships did not carry food for our great cities, many of us would starve to death, as has happened in countries like India, where transportation facilities are not equal to the task of properly distributing the food that is produced in the country.

It is not possible for us to accomplish all these tasks by our unaided strength, and we must therefore use various machines to assist us or to utilize the forces of nature. One of the great differences between savage and civilized men lies in the ability of the latter to help themselves in getting this work done. In this chapter we shall study about work and the means of accomplishing it.

187. Different methods of working. The first men doubtless did everything with their unaided hands, but soon they learned that a heavy object could be pried up with a stick more easily than it could be lifted by the hands, that a sling would throw a stone harder than the unaided hand, that a log could be rolled up an incline if it was too heavy to be lifted, and that an arrangement of rope and pulleys would make it possible to hoist very heavy weights by the use of small force. Gradually the more intelligent part of mankind has developed the use of simple machines and combinations of them, until now there is scarcely any work done without the use of some sort of mechanical contrivance. The simple machines, which are the basis of the devices which we employ to assist us in working, are the lever (fig. 89), the pulley, the inclined plane, the wheel and axle, the screw, and the wedge.

The knowledge of the use of machines is of great value to civilized man. If we had been compelled to depend on bare hands and our own physical strength alone for accomplishing all sorts of work, our present civilization could not have developed. Our condition would probably be much

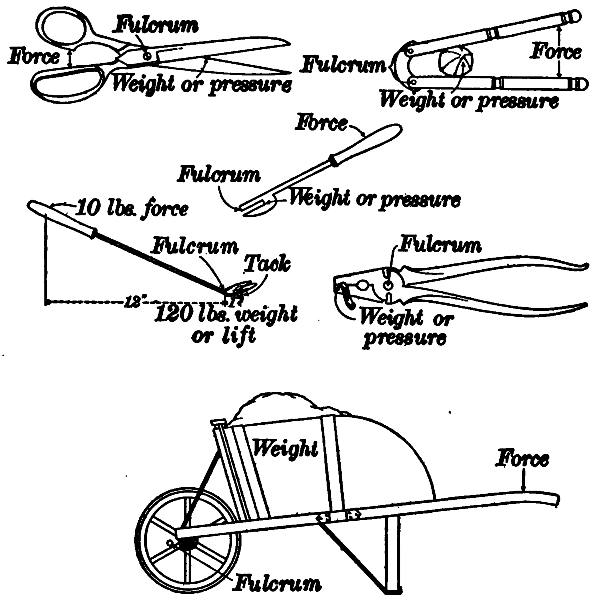


FIG. 89. Applications of the lever

The lever involves a weight to be lifted or pressure to be exerted, a force to be applied, and a fulcrum or pivotal point where the force works against the weight or pressure. Note the above and other applications of the lever and discover what advantages are derived from it

like that of the tribes in those parts of Africa, Asia, and Australia where the soil is dug with a stick and goods are transported on the backs of men. The use of various contrivances which assist in the accomplishment of work, and the knowledge of their possibilities, are among the marks which distinguish civilized people from savages. In times of war the use of machines makes war more terrible.

188. A problem in work. If a primitive man wishes to remove his dugout canoe from the water, he knows no way to do so but to lift it or drag it out. If it is too heavy fo this he may call in his neighbors and thus secure enough men to do the work. If there are no neighbors the work cannot be done.

Intelligent men have learned ways of helping themselves which enable them to overcome obstacles of this sort. Let

Fig. 90. The use of pulleys

By the use of pulleys, rope, and wheels one man may move a much greater weight than he could by pulling directly upon the object

us suppose that a boy has a boat weighing two thousand pounds and that he wishes to pull it out of the water. It is not necessary for him to call in his fellows if he understands the use of simple machines. There are several sets of appliances which might serve his purpose, but let us suppose that he has at hand some boards, rollers, rope, and two pulley blocks each of which contains two pulleys.

The boy could lay boards on the beach, with the rollers ready to support the boat, attach one pulley block to the boat and the other to a tree or post, and thread the rope through the pulleys as represented in figure 90. The boat could then be moved along the boards by pulling on the rope.

FIG. 91. Pulleys and cords

The pull on the cord is measured by the spring balance. The weight of the load is divided between strands of cord by which it is suspended. Disregarding friction, the pull on the spring balance will be one sixth as great as the pull exerted by the load

189. Decreasing friction by the use of rollers. Everyone knows that if he were to attempt to slide the boat along the board he would find a great deal of resistance. Even if the boards were horizontal instead of sloping up the beach we should find that it would take a great deal of force to move the boat. We also know that this resistance, which would be found if any attempt were made to slide the boat over the boards, is found whenever one surface is moved in contact with another surface, and that this resistance is called friction. If the surfaces are very smooth, as in the case of an ice skate, the friction is very small, but it is not wholly absent. Friction is due mainly to the fact that surfaces are never perfectly smooth and the little irregularities tend to catch on each other and thereby resist the force which is moving the object. The friction on the board would be so great that there could be little hope of moving the boat. When one object rolls over another, there is also some friction, but rolling friction is very much less than sliding friction. The boy should therefore place rollers under the boat in order to reduce the friction as much as possible, but he could not get rid of friction entirely (fig. 90).

We may speak about perfect machines (machines without friction) and calculate just what results might be obtained with them, but none such exist.

190. Some facts about pulleys. Questions must certainly arise regarding the advantage of using rope and pulleys either in moving a boat or for other purposes. Anyone who has observed the use of pulleys, as when a building is being moved through the street or when a piano is being moved to an upper floor of a house, has probably observed that the load is moved more easily by their use. It is also true that the load is not moved rapidly. Ability to move a greater load is an advantage, but the slow motion is often a disadvantage. It is important for the practical use of pulleys that one should know precisely the relation between the force exerted and the load moved, as well as understand the accompanying rate of motion. It is only by the performance of experiments with pulleys that these questions can be satisfactorily answered.

We might arrange a set of small pulleys and cord similar to the arrangement for moving the boat, but employ them for lifting a weight. It will be noted that in this arrangement, as shown in the figure, the hanging, or movable, pulley is supported by six strands of cord (fig. 91). It may be shown, first, that the force exerted by the apparatus in lifting the weight is much greater than the force applied to the free end of the cord, and second, that the weight moves a much shorter distance than does the hand which is pulling at the end of the cord.

If the distances are measured, it will be found that the hand travels six times as far as the weight in the case of the pulley system given in the figure. A measurement of the force applied at the end of the cord will show that it is a little more than one sixth of the amount which must be applied to the weight in order to lift it. There is, of course, some friction in the apparatus, and if care is taken to reduce this as much as possible, it will be found that the force applied is very little greater than one sixth of the weight lifted. We may conclude that if friction could be wholly eliminated, we should find that the ratio of the weight lifted to the force applied is 6 to 1.

We find, therefore, that in the particular pulley system which we have been studying, the applied force must move six times as far as the weight, but that if friction is neglected, it need be but one sixth as great as the resistance of the weight. With different combinations of pulleys the ratio always equals the number of strands supporting the weight.

191. Mechanical advantage of pulleys. The advantage in the use of pulleys lies in the fact that by their means a small force may be made to overcome a great resistance. This advantage is measured by the number of times which the force exerted against the resistance is greater than the force applied. In the case considered in the preceding section the *mechanical advantage* was 6. The mechanical advantage of a pulley system may be determined very readily, for it is always equal to the number of strands of rope which are supporting the weight or other resistance.

192. Work and pulley systems. If in section 188 the boy uses rope and pulleys to pull the boat out of the water, he does not escape the necessity of doing work in order to move the boat, for he must pull on the rope. The pulley system also does work upon the boat in moving it up the beach. We may call the work done by the boy in pulling on the rope the *work in*, and the work accomplished in overcoming the resistance of the boat and the friction on rope and pulleys the *work out.*

The part of the work performed in moving the boat is the *useful work*, while that wasted in overcoming friction and in the pulley system will be known as the *wasted work.*

We have learned that the force which the boy applies is less than that which is exerted upon the boat, but is the same true of the work that he puts in and the work that he gets out? Before we can solve this problem we must agree upon a definition of work and upon some means of measuring it.

193. Work defined. It is always necessary to be sure that we mean the same thing by the words we use; therefore we define work. We say that work is done when force is used to move an object any distance — as when a box is lifted from the pavement into a wagon or when a weight is pulled across the floor. Pushing the lawn mower, sweeping, pumping water, shoveling coal, are all forms of work, and in each case force is used to make something move against resistance.

194. Measurement of work. If a force of 1 pound is exerted in moving an object through a distance of 1 foot, it is plain that a certain small amount of work has been done. This amount is called 1 *foot-pound*, and this is the unit of measurement. If the distance is increased two, three, or four times, the amount of work accomplished is increased proportionally. Likewise, the increase in resistance and therefore in force exerted is accompanied by a proportional increase in work. Thus, if 1 foot-pound of work is done in lifting a pound weight 1 foot, it should be clear that 3 foot-pounds would be accomplished if the distance were 3 feet; and if in the latter case the weight were 2 pounds, the work done would be 2 × 3 foot-pounds. That is, we calculate the work by multiplying the distance by the force.

195. Calculation of work in pulley systems. We may now calculate work in and work out in the case of the pulley system used in moving the boat in section 188, in which case five and not six strands of cord are used. If we suppose that a pull of 500 pounds was necessary to move the boat and that it was moved 50 feet, the work accomplished was 25,000 foot-pounds. The applied force acted through a distance of 250 feet, which is five times the distance the resistance was moved. The force necessary, which was 100 pounds, was one fifth the resistance (neglecting friction).

It has been pointed out in a preceding section that there can be no frictionless machine. We must therefore include friction in our calculations. It is clear that the resistance

due to friction would be added to the resistance offered by the boat. The pull on the end of the rope would need to be greater than 100 pounds in order to overcome both types of resistance. The work in would be correspondingly greater. If it were necessary to pull with sufficient additional force to make the total applied force amount to 125 pounds, the total amount of work done upon the machine would be 125×250 foot-pounds, or 31,250 foot-pounds. These relations may be tabulated as follows:

	Foot-Pounds
Total work in	31,250
Useful work out	25,000
Wasted work	6,250
Total work out	31,250

The total work out is in this case and in all cases the same as the total work in. Useful work out is less than total work in.

196. Efficiency. The proportion of wasted work will not always be the same as in the problem above. If the machine is very carefully constructed the friction may be so reduced that there is very little waste. Such a machine is said to be very efficient, since it does its work with but little waste.

The efficiency of a machine is measured by the fraction of the total work done upon it which appears in the useful work accomplished by it.

$$\text{Efficiency} = \frac{\text{useful work out}}{\text{total work in}}.$$

In the particular case which we have been considering, the efficiency is calculated as follows:

$$\text{Efficiency} = \frac{25{,}000}{31{,}250}, \text{ therefore}$$

$$\text{Efficiency} = \tfrac{4}{5}, \text{ or 80 per cent.}$$

CHAPTER XVI

MECHANICAL ENERGY AND HEAT

197. Questions for Discussion. **1.** Can a boy kick a football harder by kicking it from a standing position or by running a few steps before kicking it? **2.** Would two persons walking toward one another until they came in contact strike harder than when running toward one another? **3.** Does a moving train possess energy after the engine driver shuts off steam? **4.** What becomes of the energy of a moving train when the brakes are set? **5.** Why does a gasoline engine, when it is burning a given amount of gasoline, heat up more readily when running idle than when pulling hard? **6.** If a piece of metal is pounded, or a piece of armor plate is struck by a cannon ball, the metal becomes hot. Why? **7.** Water becomes heated when it is used to cool a gasoline engine. Does this represent a waste of energy? **8.** What are the principal wastes of energy by a gasoline engine? **9.** Why does a saw become hot when in use? **10.** Does an auger heat more in soft wood or in hard? **11.** Coal has sometimes been called preserved sunshine. In what sense is this true? **12.** Would it be possible to use steam, gas, or electric engines if work that has been done by the sun were not available?

198. Capacity for doing work. In the experiments with the system of pulleys which were discussed in the preceding chapter the force was applied at the end of the cord. The same results might have been obtained in another way. A weight of some sort might have been attached to the end of the cord; if this were of the proper size it would, when released, descend and cause the load carried by the movable pulley to rise. It requires work to raise the load, and it therefore follows that the weight upon the end of the cord is able to do work. Also the pull upon the cord might have been supplied by an electric motor or by a steam engine. In either case the weight, the motor, or the

engine demonstrates that it has the ability to do work. This ability, or capacity, to perform work is called energy.

The energy possessed by a weight in a condition similar to that in our last example is utilized in clocks which are run by weights (fig. 92). In this case, when the clock is wound, the cord is wrapped on a small windlass and the weight is lifted to the top of the clock. In this position it possesses energy enough to turn the wheels of the clock for some time. When the weight has reached the bottom of its descent, the clock must be wound again. Most modern clocks are driven by coiled springs, and in this case it is the tightly coiled spring that possesses energy. A sled coasting downhill possesses energy, as may be observed if it strikes any other object on the way; a cannon ball possesses energy, which is expended upon objects in its path; a moving hammer possesses energy, which may be utilized in driving a nail.

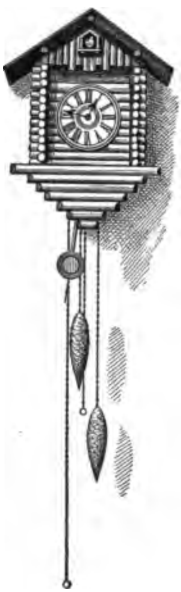


Fig. 92. A clock run by weights

199. Kinds of energy. The weight in the clock possesses energy because of its position. When it is wound up and is suspended upon the cord, it is able to descend, and in doing so it will do work in turning the wheels of the clock. When the cord is unwound, the weight is not in a position to do further work. The energy which it possessed was dependent upon its position. The same is true of the bent spring, which possesses energy by virtue of the position of the parts of the spring in relation to each other. This energy of position is called potential energy.

On the other hand, the cannon ball does not owe its energy to position at all, but to the fact that it is moving rapidly. It is the moving cannon ball and not the stationary one that

is effective for purposes of destruction. The hammer and the sled also owe their energy to motion. Energy of motion is called kinetic energy.

200. Measurement of energy. Since energy is simply the capacity to do work, it can be measured in the same units as are used to measure work; that is, energy is measured in foot-pounds.

A 5-pound weight at a height of 2 feet possesses $5 \times 2 = 10$ foot-pounds of energy, since in order to place it there a force of 5 pounds had to be applied through a distance of 2 feet. Thus the energy which a body possesses is in general equal to the work which has been done upon it.

201. Work against friction produces heat. It is a common experience that heat is produced when work is done against friction. Anyone who has attempted to break a wire by bending it back and forth has had occasion to know that it becomes very hot at the place of bending, and the harder and longer one works, the hotter the wire becomes. The same thing results from hammering a nail, and a saw becomes much heated when in use, particularly if there is much friction. If a wheel is allowed to run for some time without oil on the axle, the latter becomes very much heated. When a match is rubbed on a smooth surface, it is lighted by the heat which is produced by friction. Primitive people started their fires by use of friction between two pieces of wood. In all these cases work is done, and a part of its result appears only in the form of heat.

202. Energy transformed into heat. Careful studies have shown that in cases like the above the amount of heat developed is in proportion to the amount of energy lost in overcoming friction; that is, it is proportional to the amount of wasted work. In lifting a weight by means of pulleys a part of the energy which is exerted at the end of the rope goes to the direct raising of the weight and makes its appearance in the form of potential energy in the weight which has been

lifted. But not all of the energy which was applied to the machine can be found in the weight. You may have noticed in the calculation of work done upon a pulley system that the work out is less than the work in. The difference between the work put in and the work taken out measures the work which was necessary to overcome friction and which has

FIG. 93. The first automobile

This "gas buggy" or "horseless carriage," as it was called, built by Elwood Haynes, represents an early stage of one of the world's most remarkable accomplishments in mechanical use of heat energy — the modern automobile

resulted in the formation of heat. Careful studies have shown that the amount of energy lost and the amount of heat produced are similar.

203. Work done by heat. Most of us have noted that a steam engine, such as a railroad locomotive, must be supplied with water and coal and that the automobile engine must be supplied with gasoline (figs. 93 and 94). There are some kinds of engines which are so equipped that the escaping

steam is condensed and returned to the boiler, and in this case water need not be supplied excepting to replace leakage. Thus the water is a permanent part of the machine and not a source of energy. The coal is quite useless unless it is burned under the boiler and supplies heat to the water in the boiler. The coal or gasoline are therefore only a means of supplying heat, and heat from any other source would be just as effective; that is, if only heat is supplied to the boiler in sufficient quantity, we shall be able to get work out of the engine. Work may produce heat, as when we hammer a nail, and heat may produce work, as in the case of the steam engine.

We have shown that heat has the ability to do work; but ability to do work is the definition of energy; therefore heat is a form of energy, and work may be transformed into heat as well as into other forms of energy.

204. The engine. The machine commonly called a steam engine really consists of two principal parts — the steam engine proper and the boiler. The engine and boiler may be very closely connected, as in the railway locomotive, or they may be located at a considerable distance from each other, as in some manufacturing establishments or on board ship, where they are usually in different rooms. In the boiler, water is changed into steam by means of the heat supplied by the fire in the furnace. This steam is conveyed through a pipe to the parts of the engine where the energy is changed from heat into the mechanical energy of moving parts.

The more important facts regarding the structure and operation of a simple engine may be understood by referring to the diagram on page 189. The essentials of a steam engine are a cylinder *C*, containing a tightly fitting piston *p*, together with some means to control the admission of steam into the cylinder. The piston is free to move from end to end of the cylinder, and as it moves, the connected piston rod *r* moves with it. With the parts in the position

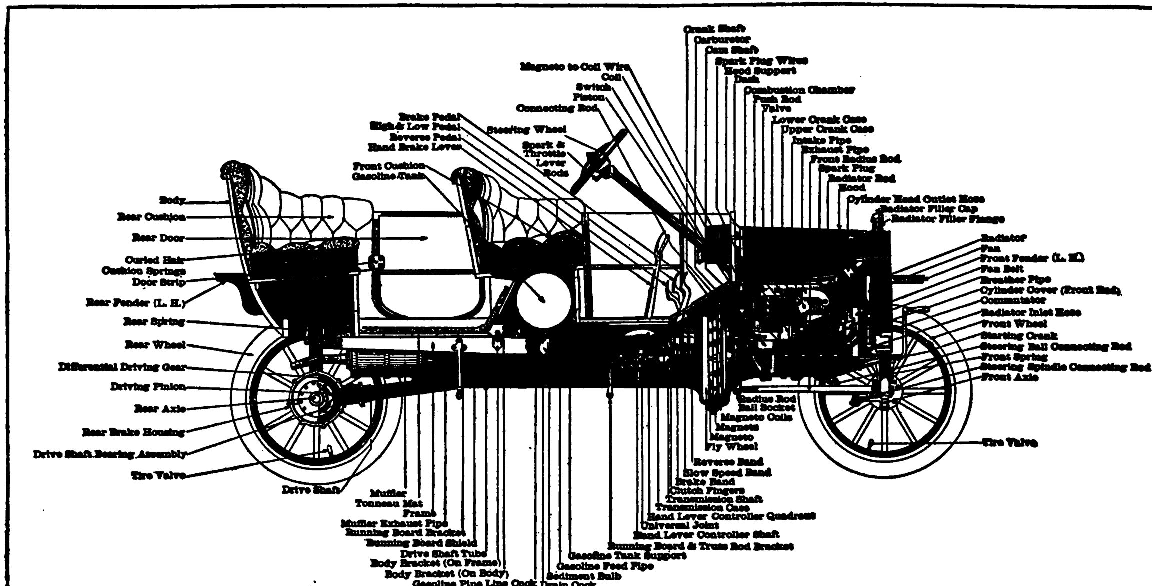


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FIG. 94. The parts of a Ford automobile

indicated in the diagram, if steam from the boiler is admitted through the pipe *st* into the steam chest *S*, it will pass through the channel *ch* into the cylinder. Here it will exert pressure upon the piston and drive it to the other end of the cylinder. Steam which may have remained in the opposite end of the cylinder from the previous stroke escapes from in front of the moving piston through the channel *ch′* under the slide valve to the exhaust pipe *e*, which leads into the

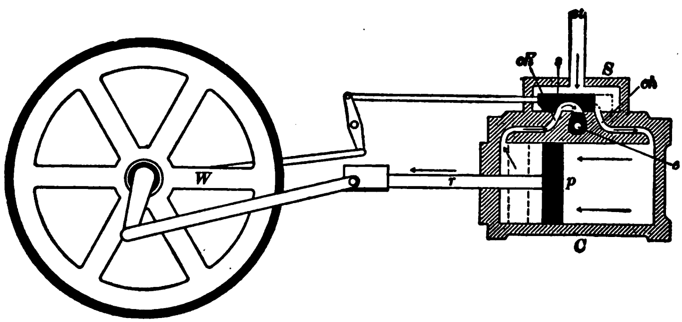


FIG. 95. The working parts of a steam engine

W, flywheel; *C*, cylinder; *S*, steam chest; *st*, steam pipe from the boiler; *ch*, *ch′*, passages for steam between steam chest and cylinder; *s*, slide valve; *p*, piston; *r*, piston rod; *e*, exhaust pipe

open air or into a condenser. A working engine is so arranged that when the piston reaches the position indicated by the dotted lines, the slide valve *s* is moved into the position indicated by the dotted lines. This, it should be noticed, prevents the steam from passing into the right-hand end of the cylinder, while at the same time it admits it to the opposite end. The pressure of the steam on the other side of the piston drives it back toward the end of the cylinder from which it started. When the piston again reaches the end of the cylinder, the slide valve returns to its original position, and this action is repeated for each stroke of the piston.

The moving piston may be connected to machinery which is to be operated. The work which is done by the piston upon the machinery is derived from the steam as it expands in the cylinder. The steam which leaves the exhaust outlet, having parted with some of its energy to the piston, is no longer as hot as it was when it entered the cylinder.

205. Transformations of energy. There are other forms of energy besides heat and mechanical energy, but we shall not discuss these at any great length. Both electricity and light are sources of energy, and potential or kinetic energy may be transformed into heat, light, or electric currents. The steam engine, together with some of the machinery that it may drive, furnishes a good illustration of the many possible transformations of energy. Let us suppose that our engine is driving a dynamo and that the electric current which the dynamo generates is employed in operating a number of lights. In that case we may start with energy in the form of heat contained in the steam. In the engine cylinder a portion of the energy is imparted to the moving piston, and this energy no longer appears in the form of heat. The energy in the moving piston is transmitted to the dynamo and is there transformed into a current of electricity. We therefore speak of an electric current as a form of energy. The current is passed through a lamp in which it gives off its energy in the form of light and heat. This energy passes off into the surrounding space and is usually lost to us.

206. Loss of energy. The amount of heat and light energy that is secured from the lights which may be operated by the dynamo is not at all equal to the amount of heat energy that was produced by the coal burned in the furnace. It may be no more than 5 per cent of the total produced by the coal. Plainly there has been a very great loss somewhere in the route that the energy has traveled in passing from the furnace to the light. This loss is not difficult to find. A great deal of heat goes up the chimney, some radiates from the

boiler and engine into the air, and some passes off in the exhaust steam. In these and other ways the steam engine wastes possibly 85 per cent or more of the energy produced by the coal. Of the energy actually utilized by the engine some is lost by friction in the engine and dynamo, showing itself in the form of heated bearings, and some is lost through the heating of the wires by the currents of electricity. Notice that in all these cases of lost energy the energy is not destroyed. It changes into some form in which it is not useful to us (usually into the form of heat which may warm the surrounding air), but it has not gone out of existence.

There is no way known by which we can destroy energy.

There is no way known by which we can create energy.

207. The source of energy. Since there is no way in which we can create energy, where does the energy come from which we are all the time using and allowing to escape from us? If a trolley car is used as an illustration, we find that it is operated by electricity. The current is generated by the dynamo, which is run by a steam engine. The engine secures its energy from coal. Plainly the coal contains energy, and we must find out where this energy came from.

Those who have studied the origin of coal tell us that it is formed of the remains of plants of former ages. The plants grew, and their dead bodies accumulated in great abundance in some places, somewhat as plant materials are accumulating now in our peat swamps. These swamps were buried by sediments which later became rocks. The plant material was buried far enough to be affected by the heat of the interior of the earth, and it was under great pressure from the rocks lying over it. All these things caused it to condense into a solid, stonelike mass, which does not at first look much as though it were made up of dead plants. A full account of the origin of coal cannot be given in this connection, but the subject will prove most interesting as an accompanying study.

Of course, if there is energy in the coal, it must have been in the plants from which the coal was made. We can burn wood to make steam in about the same way that we can burn coal. Indeed, wood is still sometimes used as fuel under boilers. Where, then, did the plants get their energy? Where do they get it now? When we were studying about how plants make their food, we found that they could do so only when they had light. Light is the power that runs the factory. By means of the energy that comes to it in the form of light, the plant is able to separate the carbon from the oxygen of the carbon dioxide and to build up those complex compounds from which its body is constructed. When we burn the wood, oxygen again unites with the other elements to form carbon dioxide, water, and other compounds, and, most important to us, the energy that was put into the compound is released in the form of heat.

The sun, then, is the source of the energy which we find stored up in wood and in coal. If we were to take any other example and trace back the energy, we should in all cases arrive at the sun as the last term in our series. The sun is the great source of the world's energy. The sun is the engine that runs the trolley car.

208. Amount of energy from the sun. Some careful studies have been made to find out how much energy the earth receives from the sun. It is believed that the amount is equivalent to more than 200,000,000 horse power for each inhabitant of the earth. It is this continual supply of energy from the sun that maintains the temperature of the earth's surface, evaporates water, causes convectional air currents, and provides the energy for photosynthesis. Since the earth is continually giving off heat to the surrounding space, it is continually losing energy. The part of the sun's energy which is stored up in plants and animals, or used in evaporating water, supplies most of the energy which is used by man in accomplishing his work. This is probably not more

than a thousandth part of the whole. It has been estimated that enough energy falls upon the deck of a steamship in tropical regions to propel it at a rate of several miles per hour if there were some way in which all this energy could be made useful. There have been many attempts to construct "solar engines," which should use this supply of energy directly, but so far none of them has been very successful.

Of course only a small part of the energy given off by the sun comes to the earth, — 1 part in 2,000,000,000, — and therefore the sun must be giving off energy very rapidly. Perhaps its supply of energy is growing less, but it is so big that the loss has not been great enough to be noticed during the short time that men have been making careful observations. Although the sun must finally lose so much energy that it will not be able to give off as much heat and light as it does now, it is estimated that a sufficient change to affect life upon the earth will not occur for many thousands of years.

209. Energy and work in living things. Many of the instances of work which have been given in the preceding chapters are examples of work accomplished by living beings. If you climb a flight of steps, push a lawn mower, or saw a board, you are doing work; you are expending energy. Even when you are sitting still or when you are sleeping, there is some expenditure of energy, for the heart continues to beat, you continue to breathe, and heat is radiated from your body. The lower animals expend energy in similar ways. Plants too use energy, for they open and close their flowers, move their leaves, lift large quantities of water from the soil to the leaves, and engage in many other activities. Energy is supplied to living things through food somewhat as energy is supplied to a steam engine through the agency of the coal which is put into the furnace. Since the origin of foods can be traced back to the manufacture of carbohydrates

through the aid of the sun's energy, it is not difficult to see that the sun is the ultimate source of energy for all the activities of living things. In connection with the preceding study of work and energy it is important that we consider the relation of the earth and sun to other bodies which radiate light and heat. However, since electricity and electrical appliances occupy so large a place in the work and pleasures of modern life, electricity and electrical work will be discussed next, and then we shall consider some elementary questions in astronomy.

CHAPTER XVII

HEAT AND LIGHT FROM ELECTRIC CURRENTS

210. Questions for Discussion. **1.** Which is cheaper to operate, a tungsten or a carbon lamp? Why? **2.** Why are electric-lamp wires covered with rubber and cloth? **3.** What are the sparks sometimes observed between the trolley wire and wheel? **4.** Why are electric wires often put in metal pipes? **5.** Why are glass insulators used on telephone and telegraph lines? **6.** Are electric-heating devices expensive to use as compared with devices which use coal and gas? **7.** How should dry cells be connected for a doorbell circuit? **8.** How does a push button operate the electric bell? **9.** Is there any danger in having electric wires in a house? **10.** How is a flashlight battery made? **11.** What is a fuse? Why is it used? **12.** Why are ammeters used on automobiles? **13.** How can telephones be protected from damage due to lightning? **14.** What is a short circuit? Is a short circuit dangerous? **15.** How does the watt-hour meter aid in finding the cost of electric energy? **16.** What does electric energy cost in an ordinary residence? in a store? **17.** How is an electric iron constructed? **18.** Why is a spark plug used in a gas engine? **19.** How is a motion-picture machine constructed? **20.** How is the electric current supplied to street lamps? **21.** How is an electric fire-alarm system constructed?

211. Light and heat. Until a few decades ago artificial light which was used in such places as homes and factories was produced by a flame from oil, gas, or a candle. These sources of light still have extensive uses, but light by use of electricity has become more common than other kinds of artificial light. In the older forms of artificial light it is readily noticed that heat as well as light is produced. In order that the light may be at its maximum, the heat that is lost must be at its minimum. Some substances may be heated to a temperature at which they will give off light without melting or burning, while other substances which burn while giving off

light are consumed and cease to be useful as light producers. There are very few materials which will endure heating to the white heat which is observed in the best electric lamps. Tungsten and a few other metals may be so heated, but even in the best tungsten lamps the amount of light given off represents about 4 per cent of the energy used in the lamp; the remaining 96 per cent is given off as heat.

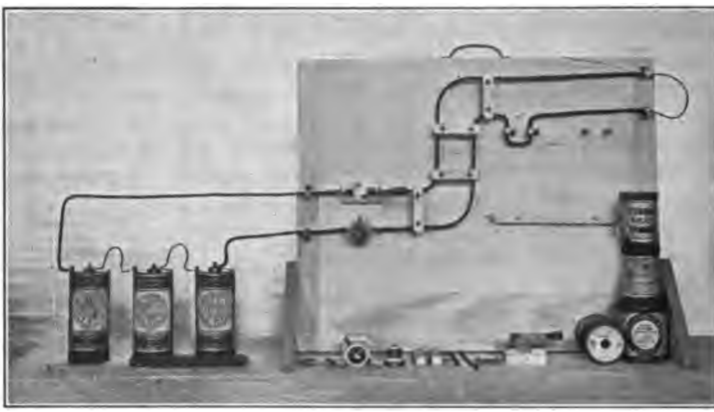


FIG. 96. Apparatus for study of an electric circuit

The handmade mounting board with porcelain cleats, binding posts with screws, and switch provides a simple and effective means of studying electricity. The electric generator consists of three dry cells connected by insulated copper wire. At the right, above, is a loop of small wire fastened to the binding posts so that the heating effect of electricity may be studied; at the right, below, are four spools of wire of different sizes for use in the same experiment

Is the heating and lighting effect peculiar to the wire in a lamp or can it be produced in any wire? To answer this question we must learn something about the materials to be used, most of which can be purchased at an ordinary hardware store. In figure 96 some of these materials are arranged so as to make a complete path for the electric current. When all the wires are properly connected (the covering or insulation must be removed to secure good metallic contact), as shown in the figure, a loop of wire fastened to the upper

right-hand binding posts completes the metal path. The current is said to pass from the carbon of the right-hand one of the three cells, flowing through the circuit to the zinc of the first cell, and completes the path by passing through the cells.

If a foot of copper wire (No. 30, which is one hundredth of an inch in diameter) is inserted in the binding posts and the switch closed, the wire becomes red-hot and melts. We must learn how to control the electric current in order to prevent the wires from being destroyed. If four feet of the wire is placed in the circuit, the heating effect is greatly reduced. The results of common experiments with other wires are given in the table below.

Kind of Wire	Size	Diameter	Length of Wire used	Results
German silver, double cotton covered	No. 30	.01 in.	6 in. 24 in.	Melts Hot
Fuse wire, the bare wire .	No. 20	.032 in.	3 in. 12 in.	Melts Melts
Chromel, the bare wire .	No. 30	.01 in.	3 in. 12 in.	Red heat Warm

Since electric wires may become hot, all electric wires in buildings, automobiles, motor boats, etc. should be placed in metal tubes or conduits or otherwise arranged to protect against danger.

212. The use of fuses for safety. In the electric circuit there is a piece of soft metal in the fuse plug (fig. 97, *D*) which makes an important use of the heating effect just discussed. The current in the circuit must pass through this ribbon, which is a mixture of lead and tin or of other metals. If the current becomes excessive the metal melts and thus breaks the connection, but the melting occurs at a much lower temperature than that of the wires in the previous experiment. This provides a means of inserting a sort of

"safety valve" in the electric circuit. This fuse wire is made and labeled in various sizes so as to limit the strength of the current to any selected value. Such a fuse is often to be found near the electric meters in a building, and may be observed but should not be disturbed.

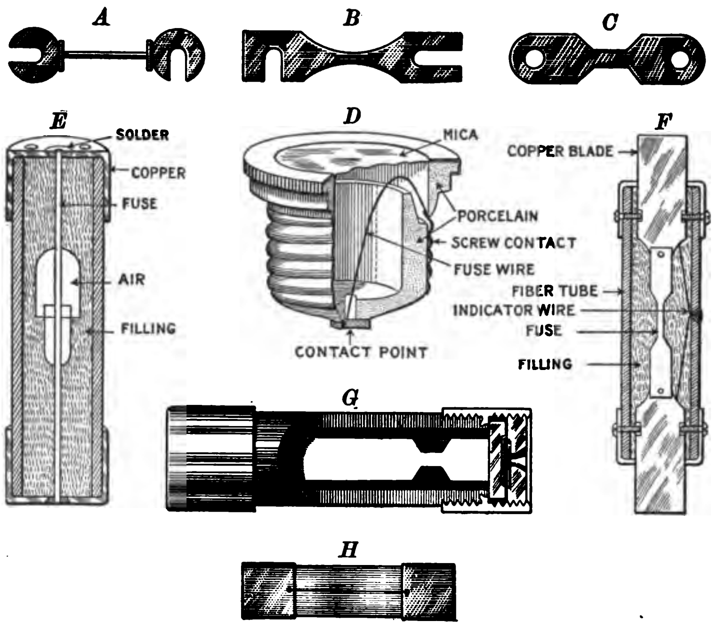


Fig. 97. Different types of fuses

A–C, simple fuses designed to hook over connecting posts; *D*, an ordinary screw-plug fuse; *E–H*, fuses to be slipped into fuse openings so that the fuse ends connect with electric wires

The open-link fuse (fig. 97, *A*, *B*, *C*) is unreliable and often unsatisfactory because little drops of molten metal deface the supporting board and may injure the operator. Another type of fuse contains a metal wire or strip which can be renewed, but this is covered with a tube of fiber (fig. 97, *G*). Other fuses are filled with a material which does not catch fire when the fuse burns out or explodes (fig. 97, *E*, *F*). Telephones

are also protected by fuses (fig. 97, *H*). All electric circuits and the devices and appliances in them are protected either by fuses or by automatic switches which open before the current reaches a strength that will do damage. Insurance companies do not take risks upon buildings that are improperly wired. For experimental work it is wise to use a fuse rated at a much lower value than that which the instrument or device can carry safely, since certain fuses often carry a momentary current from 50 to 100 per cent greater than the rated value marked on the label.

When the currents become very large, as those required for street-car motors or commercial machinery, a device called a "circuit breaker" is used. This is essentially an automatic switch which opens, often with considerable noise, when the current reaches a certain value.

213. How electric circuits are opened and closed. We often push an electric button or turn a switch of an electric-light bulb without knowing what we are really doing. These are forms of electric switches. The essential thing in all electric switches is that they complete the electric path by bringing two conducting metal surfaces together. This is shown by means of the knife switch in figure 96. If we place such substances as a silver dime, a copper penny, or a piece of brass firmly between the blade of the switch and the metallic jaws, the current flows through the circuit. Such substances are called good conductors of electricity. Other materials, such as glass, porcelain, mica, cloth, or rubber, which do not permit the current to flow, are called nonconductors or insulators. Where have you seen insulators used?

In speaking of an electric circuit we often say that it is an open circuit, a closed circuit, or a short circuit. An open circuit is one in which the metallic wires or other conductors are broken at one or more points so that there is not a complete path for the electricity. A closed circuit is obtained when the switch blade is brought into contact

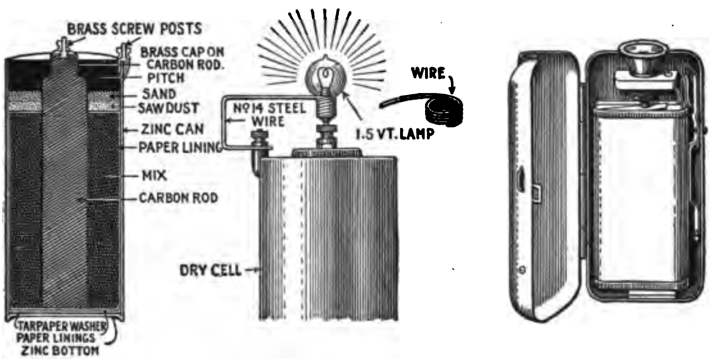
with the metal jaws, making the metal circuit continuous. A closed circuit is obtained also when the button of an electric-bell circuit is pushed and when the switch of an incandescent lamp is turned on so that the lamp gives light.

A short circuit can be illustrated with materials, as shown in figure 96, by placing a piece of heavy copper wire on the zinc of the first dry cell and on the carbon of the third dry cell. Under these conditions very little current flows through the usual course because the short, heavy piece of copper wire permits most of the current to pass through it. In this case the electricity does not perform the desired work, and it may be said to be leaking, but this is not strictly true. Although electricity takes all paths, the greater quantity takes the path through the thick, short conductor. A short circuit is produced whenever any piece of metal or other conductor permits the electric current — at least a large portion of it — to be diverted from its regular path. The short circuit is a condition which electricians try to avoid, since the current may become so excessive that great damage results. Fuses are usually melted, and a considerable flash and a startling noise may accompany the momentary short circuit.

214. The dry cell and its uses. There are many different kinds of electric cells, some of which are easily made. The dry cell (fig. 98, *A*) consists of a zinc can which contains a rod of carbon surrounded by a mixture of black manganese dioxide and powdered carbon. Within the zinc can is a paste of sal ammoniac (ammonium chloride) and water. The ammonium-chloride solution or paste is the most important material in the cell, but the manganese dioxide and powdered carbon are necessary for the best operation. In the zinc of an old dry cell many holes may be seen. Most of the metal has disappeared, since it has been consumed by chemical change to furnish the energy to drive the electricity through the cell and the circuit, much as coal is burned to furnish

the energy used in forcing water through pipes. An old dry cell may often be improved for a short time by punching a hole in the top and adding water.

There are only two practical sources of electricity, primary cells and dynamos. The former are useful where small, intermittent currents are desired for doorbells, toys, clocks, telephones, and spark coils; the latter are required for the cheaper energy for domestic and commercial purposes. Dry



A *B* *C*

Fig. 98. Dry cells

A, longitudinal section of a dry cell; *B*, simple flashlight which uses a dry cell, *C*, pocket flashlight similar to *B* except that it is inclosed

cells of the usual size are now manufactured in the United States at the rate of about fifty millions each year. Great quantities of smaller cells are used in flashlights.

215. How to make a common kind of electric circuit. The question often arises, What is the best way to connect dry cells? In figure 96 the current is considered as leaving the carbon (known as the +, or positive, terminal) of the right-hand cell, passing along the wire to the fuse, then through the wires and back to the switch, then to the zinc (known as the –, or negative, terminal) of the left-hand cell. The electricity passes through the cell from zinc to carbon, but

from carbon to zinc outside of it. The current which goes through any part of this path goes through all parts. The dry cells are said to be connected in series to form a dry-cell battery. The cells in a flashlight battery are arranged in this manner. This is a common type of connection, which is used in batteries for doorbell circuits, gasoline engines, telephones, program clocks, and automobiles.

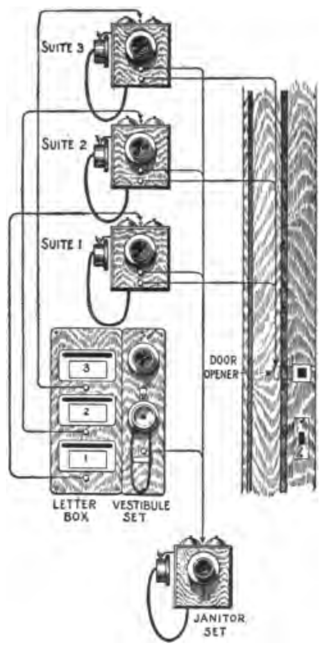


FIG. 99. Electric bells in an apartment building

The wires for the parallel circuit are not shown. The lines indicate what takes place when a given push button is operated

The tungsten lamps or the arc lamps on the street are usually connected so that the current flows through each lamp in succession, and they are said to be connected in series. Decorative lamps for Christmas trees are also connected in series. The chief objection to this kind of circuit is that if one lamp breaks, none will give light. When the electricity passes from the generator or battery and returns through only one path, the path is called a series circuit.

216. Another kind of circuit. The dry cells (fig. 98) might have been connected by joining the carbons of the cells with a single wire and connecting the zincs in a similar manner. The electric current now flows from all the carbons, or positive terminals, through the circuit back to all the zincs, or negative terminals, and the cells are said to be connected in parallel or multiple. This type, though not so common for cells as the series connection, has extensive uses. A parallel circuit is peculiar in that there

is more than one branch through which the electricity may pass. It may be compared to the stream of water about an island in a river. Part of the water flows around one side of the island, and the remainder goes around the other side, but the two streams join lower in the channel and become one. If there are several islands in the stream at this point we might imagine a current of water broken up into numerous

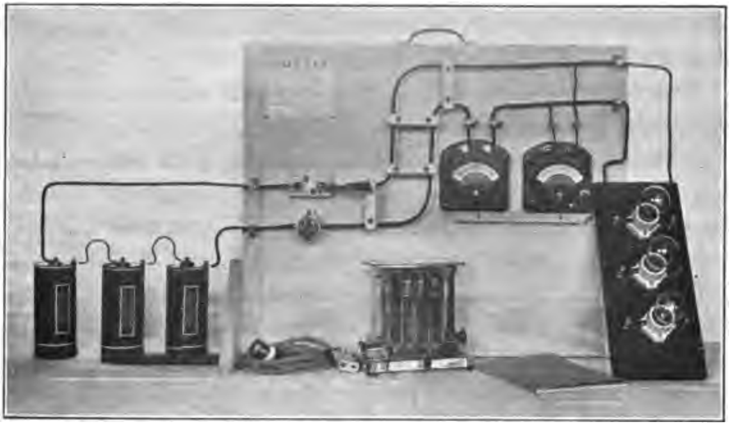


FIG. 100. Demonstration of series and parallel connections

The strength of current (amperes) is read from the ammeter on the left, the electrical pressure (volts) from the voltmeter on the right. The sign lamps shown are rated at eleven volts. The electric toaster is made of high-resistance wire or ribbon

small streams about the islands, but the total quantity above and below remaining the same. This is exactly what occurs in the parallel circuits of an ordinary residence. There are many branches of the electric circuit in the various rooms, but all the electricity that goes into these branches from the main wire on one side flows out on a wire connected to the other side of the circuit. Practically all incandescent lamps, electric bells, and buzzers are arranged in parallel. The great advantage of the parallel circuit is that one electrical appliance may be operated independently of any other device (fig. 99).

217. Series and parallel connections. The advantages and disadvantages of series and parallel connections can be shown with the apparatus in figure 100. In order to measure these effects we must use the two instruments shown upon the mounting board. That on the left is called an ammeter, that on the right a voltmeter. The ammeter is connected in series in the main circuit to be studied. The voltmeter is arranged in parallel (shown by smaller wires) across the same circuit. An ammeter is always connected in series, while a voltmeter is placed in parallel with the circuit.

The tungsten sign lamps can be used with ordinary dry cells and will enable us to perform several experiments. The dry cells and lamps can be connected as suggested in the table below. When the switch is closed, the pointer on the ammeter scale moves a certain distance and the indicator on the voltmeter scale does the same. The ammeter pointer on an automobile is often noted to behave in the same manner. The number of amperes designates the amount of current in a circuit; the volts refer to the electrical pressure causing the electricity to flow. The values for the amperes (ammeter reading) and the volts (voltmeter reading) for various combinations are given in the following table:

Trial	Source of Current	How Lamps are Arranged in Circuit	Electrical Pressure (Volts)	Current (Amperes)	Resistance Ohms
A (1)	3 cells, series	1 lamp	4.4	.4	11
(2)	2 cells, series	1 lamp	2.8	.24	11
B (1)	3 cells, series	2 lamps, parallel	4.3	.78	5.5
(2)	3 cells, series	3 lamps, parallel	4.3	1.2	3.6
C (1)	2 cells, parallel	3 lamps, parallel	1.4	.38	3.6
(2)	3 cells, parallel	3 lamps, parallel	1.4	.38	3.6

In the table above we learn from part *A* that three dry cells arranged in series give a higher voltage than two cells and send more current through the circuit. Part *B* shows that

three incandescent lamps connected in parallel use more current than two lamps, but the voltage is unchanged. Part *C* shows that no change in voltage occurs when the number of cells connected in parallel is increased. Before discussing the last column of the table, we must understand certain units of measurement.

218. Units used in measuring electricity. Air and water pressures are usually measured in pounds per square inch. When the pressure is high the water faucet or the compressed-air tube delivers a greater quantity than when the pressure is low. The unit of electrical pressure (electromotive force) is called the volt in honor of Count Alessandro Volta (1745–1827), a great Italian physicist. The value of the volt is slightly less than that produced by an ordinary dry cell. Ordinary storage batteries may operate at 4, 6, or 12 volts; incandescent lamps at 10, 55, 110, and 220 volts; and street-car motors at 400 to 600 volts.

The flow of water may be measured as the number of gallons passing through a pipe per second. Similarly, when a certain quantity of electricity passes through a wire in a second, the current is said to have a value of 1 ampere. This term is selected in honor of a great French physicist, André Marie Ampère (1775–1836).

An idea of the amount of current which an ampere represents may be obtained from the following illustrations: The old style 16 candle-power incandescent lamp (carbon filament) required about .5 ampere, and the common 60-watt tungsten lamp uses about .5 ampere. An average electric bell uses $\frac{1}{10}$ ampere. A dry cell when short-circuited for an instant will give from 15 to 30 amperes. Many of the fuses in residences are designed to carry 6 amperes safely; others are rated to carry from 1 to 25 amperes; special types carry large currents.

It is well to remember also that there may be a great pressure and no current. If the valve in the water main is

closed no water can flow, and if the electric switch is open there can be no flow of the current. The nature of the path, or the resistance, has a great influence on the current. The greater the resistance, the less the current, and vice versa. The unit for measuring this resistance is called the ohm in honor of Georg Simon Ohm (1787–1854), a noted German physicist. The ohm is approximately the resistance of 160 feet of No. 18 copper wire of the variety used for lamp cords. Other values are shown in the table on page 204.

All these facts are summarized in the following law, which was announced by Ohm in 1826, this law showing the relations between current (I), electromotive force (E), and resistance (R). The values for the resistances in the last column of the table on page 204 were calculated by means of the second equation.

Ohm's Law

$$\text{Current} = \frac{\text{electromotive force}}{\text{resistance}}$$

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}} \qquad I = \frac{E}{R}$$

$$\text{Resistance} = \frac{\text{electromotive force}}{\text{current}}$$

$$\text{Ohms} = \frac{\text{volts}}{\text{amperes}} \qquad R = \frac{E}{I}$$

$$\text{Electromotive force} = \text{current} \times \text{resistance}$$

$$\text{Volts} = \text{amperes} \times \text{ohms} \qquad E = IR$$

This formula is used extensively in all electrical work.

219. Practical uses of voltmeters and ammeters. The voltmeter and ammeter are as necessary in the use of electricity as scales are in the grocery business. The instruments shown in figure 100 are modified forms of voltmeters and ammeters designed for automobile service.[1] They consist of a U-shaped

[1] Large charts illustrating ammeters and voltmeters may usually be obtained free from supply companies such as the Weston Electrical Instrument Company, Newark, N.J.

magnet, a coil of wire (with an iron core in it) to which a pointer is attached, a spring to return the pointer to zero, and a table of figures or a scale.

Figure 100 shows how the current enters the ammeter. It enters at the positive terminal and passes into the ammeter through a short conductor (low resistance) to the main line. A small fraction of this current goes through a movable coil of wire located between the ends of a magnet. The slight rotation of the coil is magnified, and is registered by the pointer upon the scale.

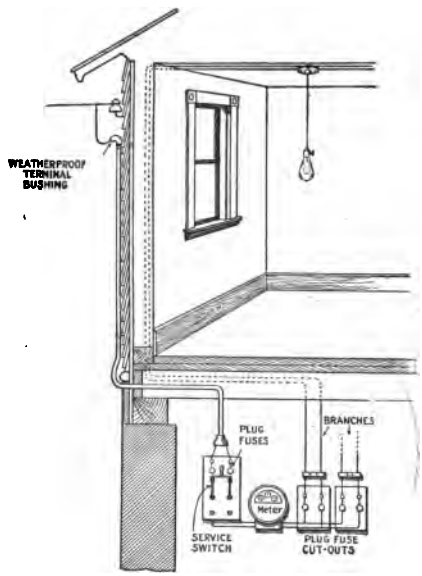


FIG. 101. How electricity is brought into the house

Note the entrance conduit, the service switch, the meter, the fuse plugs, and the courses followed by the distributing wires

The voltmeter differs from the ammeter in two important respects: it is connected in parallel with the main circuit, and it has a coil of wire (resistor) of very high resistance in order that only a small fraction of the current in the main circuit may pass through the instrument. Electrical instruments, like other machines, vary greatly in size, accuracy, and price. The ammeter should be carefully used and should under no condition be short-circuited across the terminals of any cell or generator.

These two measuring devices enable us to determine the condition of an electric circuit. The resistance of any conductor can be readily found by using Ohm's law. From a wide range of resistance wires one may be selected to carry

any desired strength of current. The regulating device known as a rheostat or a resistance controller and the devices for measuring currents are in such constant use that several million dollars' worth of them are sold annually.

In power stations these instruments are made with large proportions in order that the scale may be seen from a distance. In the automobile garage they may be found on the

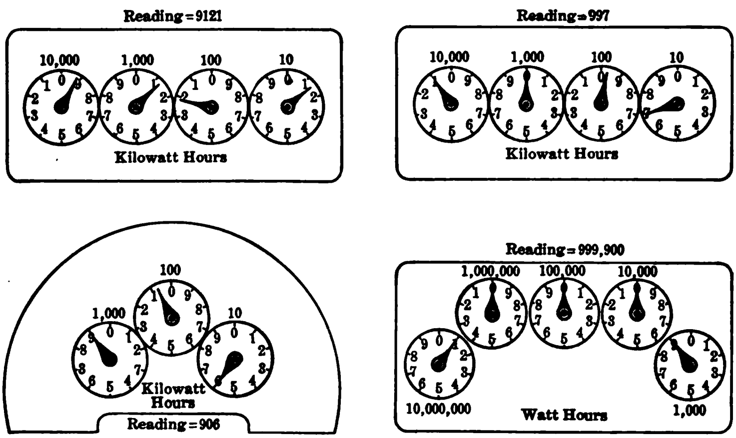


Fig. 102. Different types of watt-hour meter dials

To read the dials of the upper left-hand meter, begin with the right-hand pointer. The last figure passed by the pointer is 1; on the second dial, 2; on the third dial, 1; on the fourth dial, 9. Therefore the reading is 9121. Read the other meters the dials of which are shown

slate or marble switchboard where the storage batteries are charged. The so-called "alternating current" (the direction of the flow of the current reverses from 50 to 120 times each second) requires measuring instruments different from those just described.

220. How to read the watt-hour meter. Service wires from the main lines (fig. 101) are brought into the home, shop, or factory. Near the place of entrance the watt-hour meter will be found. Although this instrument may appear to be a rather complicated piece of apparatus, it is really a very

small motor — an ammeter and voltmeter combined — for the purpose of measuring the energy of the electric currents.

In section 195 there was a discussion of the units of work. That is,

$$\text{Work done} = \text{force (pounds)} \times \text{distance (feet)},$$

and the unit of work is the foot-pound. The unit of power is 550 foot-pounds per second, which is known as one horse power. It must be understood that the unit of power is an arbitrarily determined unit, but as necessary as are other units of measurement.

Units of work and power in the metric system may be obtained in the same manner.

$$\text{Work done} = \text{force (grams)} \times \text{distance (centimeters)}.$$

The unit of work is the gram centimeter, and the unit of power is 10,200 gram centimeters per second, or 1 watt.

The watt is a rather small unit of power; therefore in practice the kilowatt (1000 watts) is used. One horse power is equivalent to 746 watts. The watt was named in honor of James Watt (1736–1819), who invented the steam engine.

The number of watts used in a direct-current circuit can be obtained by multiplying the amperes by the volts. For example, the power consumed by the electric toaster (fig. 100) is calculated as follows:

$$\begin{aligned} \text{Watts} &= \text{amperes} \times \text{volts} \\ \text{Watts} &= 5 \times 110 \\ \text{Watts} &= 550 \\ 550 \text{ watts} &= .55 \text{ kilowatt} \end{aligned}$$

If the cost of electricity is ten cents per kilowatt for an hour, the cost of operating the toaster will be five and one-half cents per hour, eleven cents for two hours, etc. The cost of energy in an alternating-current circuit, which is more commonly used, is obtained by means of the watt-hour meter instead of by the method described above. Watt-hour meters are made for both direct-current and alternating-current circuits.

In figure 102 the dials for an ordinary watt-hour meter are shown. In the meters in most common use there are figures above or below each dial to indicate the value of a complete rotation of the pointer on that dial. If there are ten divisions on the dial, each division is one tenth of the value of the number near the dial. Some of the pointers rotate clockwise and some counter-clockwise, and the direction must be noted in each case. One revolution of the pointer on any right-hand dial is equal in value to one-tenth revolution on the dial next to it on the left. Sometimes a multiplying number is given, in which case the actual reading must be so multiplied to determine the correct values. Finally, the reading last made must be obtained and deducted from the present reading in order to show the correct amount of energy used since the last reading. The following example will show how the cost is computed:

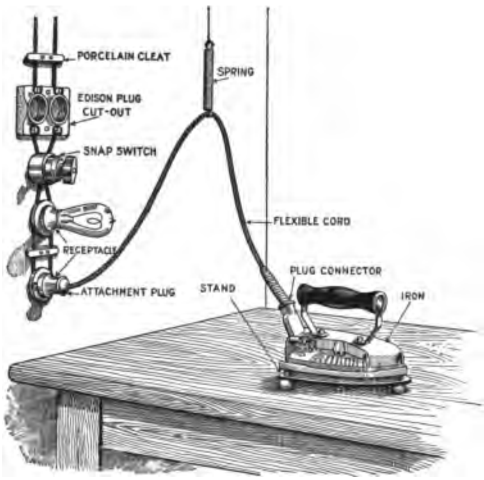


FIG. 103. An electric flatiron

The resistance wire shown in the iron is heated by the current. Devices are also shown for attaching the cord for use of a lamp, for turning the current on and off, and for attaching fuse plugs

Reading (present month)	= 9121	kilowatt hours
Reading (last month)	= 9101	kilowatt hours
Difference	= 20	kilowatt hours

20 kilowatt hours at 10 cents per kilowatt hour = $2. The bill for the month is $2.

221. Uses of electric heating devices. The electric smoothing iron (fig. 103) is much more convenient for those whose homes are provided with electricity than are the irons heated by other methods. Furthermore, the electric iron when in use is kept constantly at the desired temperature, so that there is a saving of the time usually consumed in changing or reheating the irons when coal or gas is used as the source

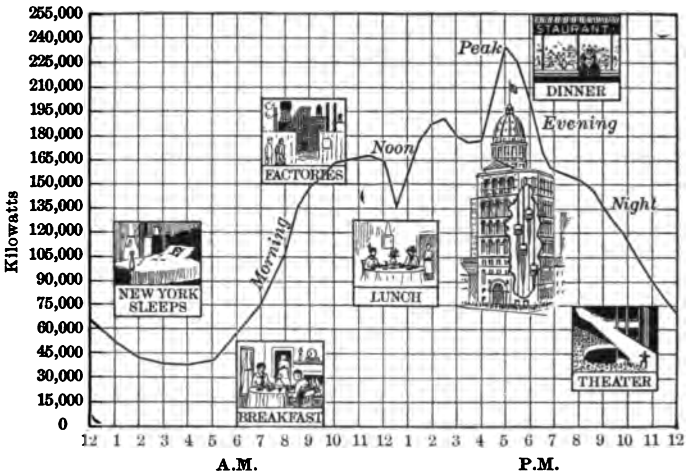


Fig. 104. Use of electricity at different times of day

The diagram represents a typical day's demands for electricity in New York City. Redrawn from *The Electrical Experimenter*

of heat. Because of these advantages, as well as the increased cleanliness, electric irons are coming into common use in commercial laundries and clothing establishments as well as in private homes. Care must be taken not to allow the current to flow while the iron is not in use. Fires may be started in this manner.

As a source of heat and light, electricity is more expensive than gas, but there are compensations in the form of efficiency, adaptability, and cleanliness. The number of kilowatts used in New York City during a typical day and night is shown

in figure 104. In the following list of common devices for the use of electricity there are also given the number of watts and amperes consumed per hour and the approximate cost per hour for each device.

Cost of Operating Heating Devices

(Computed on a cost basis of ten cents per kilowatt hour)

DOMESTIC DEVICES

Device	Amperes taken at 110 Volts	Watts consumed	Cost in Cents per Hour
Mazda B lamp, vacuum type, 47 candle power	.54	60	$0.006
Mazda C lamp, gas filled, 1430 candle power	9.00	1000	$0.100
Radiant toaster	5.45	600	$0.060
Chafing dish	5.45	600	$0.060
Disk stove	5.45	600	$0.060
6-pound smoothing iron	5.00	550	$0.055
8-inch fan (full speed)	.22	25	$0.002
Sewing-machine motor	.50	55	$0.005
Washing-machine motor	1.82	200	$0.020
Heating pad	.20–.40	22–44	$0.005
Radiant grill	5.45	600	$0.060
Ranges (2 to 4 people)	9.01–40.90	1000–4500	$0.100–$0.450

COMMERCIAL DEVICES

Device	Amperes taken at 110 Volts	Watts consumed	Cost in Cents per Hour
Glue pots	1.0–8.0	110–880	$0.011–$0.088
Instrument sterilizers	3.2–4.5	350–500	$0.035–$0.050
Sealing wax pots, .5–1.5 pt.	1.6–2.7	175–300	$0.017–$0.030
Soldering irons, various sizes	.9–4.1	100–450	$0.010–$0.045
Vulcanizers for automobile tires	.9–4.1	110–450	$0.010–$0.045

222. Electric advertising signs. The electric sign is one of the wonders of modern life. Lamps are arranged so as to spell the name of the article or firm advertised. Switches

are operated by a motor so that groups of lamps are turned on at short intervals, giving many marvelous and often deceptive effects. Almost every journey into one of the main streets of a large city discovers new devices for using electricity in advertising.

223. Other devices utilizing heating effects. There are many appliances which utilize the heating effect of an electric current. Probably the most important of these is the electric lamp. The first incandescent lamps were made in 1879 by Thomas A. Edison. The electric current was passed through a piece of charred bamboo fiber, which was placed in a vacuum. This filament was used until about 1894, when a process for improving the carbon was discovered. The metal filament lamps were introduced about 1906 and are still undergoing improvement.

FIG. 105. An ornamental lamp post

Note the lead-covered conduit through which the electric wires lead to the tungsten lamp

The carbon lamp is rapidly going out of use. The improved carbon lamp, with metallized filament, is used to some extent where low first cost is considered. The tantalum lamp has been displaced by the tungsten lamp, and 80 per cent of the lamps now used are said to be of the tungsten type. The vacuum lamp, in sizes below 100 watts, is used in electric signs, automobiles, flashlights, electric cars, and railway coaches. The gas-filled tungsten lamp is used for

street lighting (fig. 105), for locomotive and street-car headlights, for projectors for lighting buildings and monuments, and for stereopticons. A lamp is now on the market which operates successfully at 6 volts (24 watts) from a storage battery. Tungsten lamps requiring 20 amperes at 30 volts are used in motion-picture machines. Special lamps with a blue bulb are made for photographic purposes.

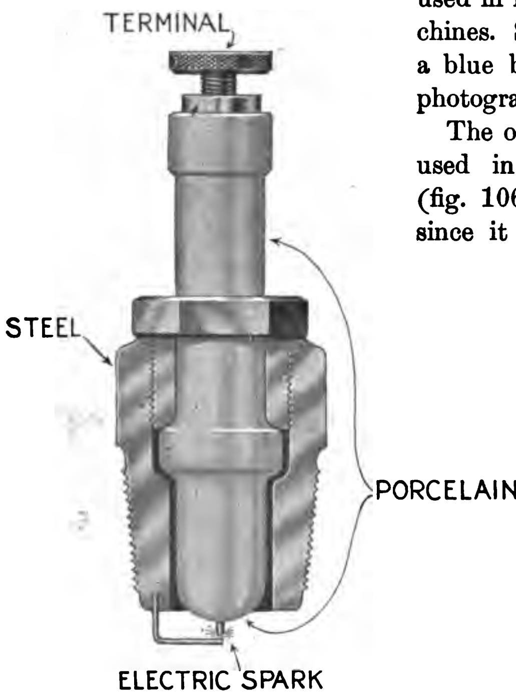


FIG. 106. An automobile spark plug

The ordinary spark plug used in the gas engine (fig. 106) is of interest, since it is said that there are now nearly 5,000,000 automobiles in use in America — an average of about one motor car for each twenty persons. This spark device consists of a break in a circuit caused by separating two wires. An electric spark similar to that which can often be obtained by opening a knife switch is caused to jump between the metallic tips. The gas mixture is exploded when this spark occurs.

224. The motion-picture machine. The invention of the motion-picture machine (fig. 107) is generally credited to Eadweard Muybridge, who was born in England. Muybridge came to America, and in 1872, while at work in California

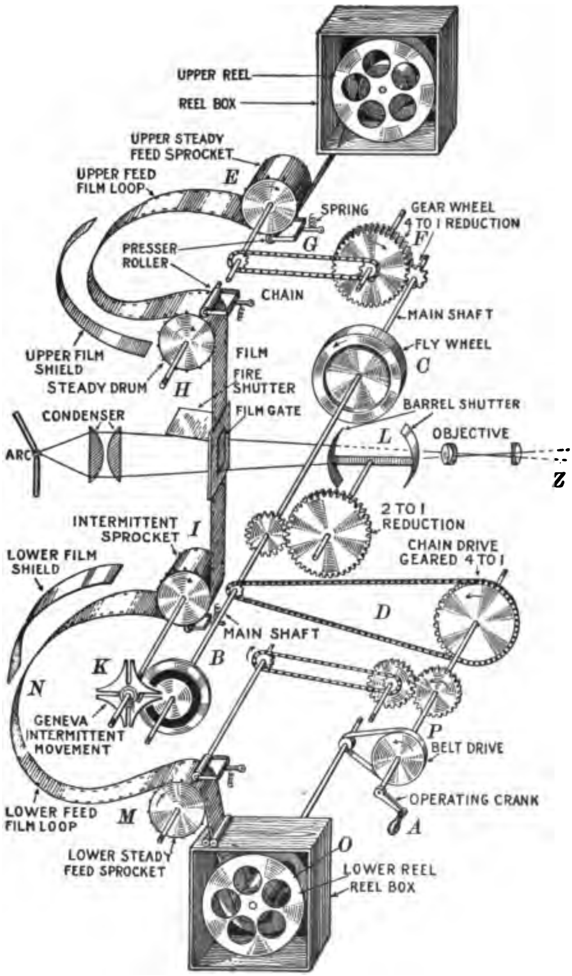


Fig. 107. The mechanism of a motion-picture machine

Redrawn from Hawkins's "Electrical Guide"

on a general photographic survey of the Pacific coast, became interested in motion pictures. One of the debated problems of that time was whether a horse in running ever has all four feet off the ground at the same instant. Later, at the University of Pennsylvania, a very elaborate studio was constructed to take pictures of moving objects. Several thousand views were made of birds, horses, wild animals, and human beings in motion. These pictures were shown at what was probably the first motion-picture theater, at the World's Columbian Exposition held in Chicago, in 1893.

Motion pictures depend upon the persistence of vision in the eye; that is, the image of a moving object does not disappear at once, but remains for a time, the period of persistence depending partly upon the condition of the light and exposure. There are many familiar illustrations of this fact; for example, a ring of fire is produced by whirling a burning stick, and the spokes of a wheel merge into a disk at a certain speed.

How are the pictures taken and projected upon the screen? The pictures of the original moving objects are obtained by means of a camera of a special design, in which a photographic film is exposed by a revolving mechanism that makes from 16 to 120 pictures per second. This film, when developed, forms the semitransparent negative, from which a roll of positive pictures is printed. The positive film, which now bears the small images, being printed on celluloid, is partially transparent. When projected on the screen at the proper rate (which varies from 16 to 120 per second) by means of a suitable lantern, the rapid succession of still pictures gives the sensation of motion. A rotating shutter prevents the light from striking the screen while the next picture is being moved into position. Colored effects are obtained by passing the light through tinted and transparent shutters. Since the celluloid is combustible, precaution is taken to make the machine booth fireproof.

CHAPTER XVIII

CHEMICAL EFFECTS OF ELECTRIC CURRENTS

225. Questions for Discussion. **1.** How are knives and spoons plated with silver? **2.** Why are articles plated with nickel? **3.** How are electrotypes made? **4.** What materials are needed to plate a piece of steel with copper? **5.** How is an automobile storage battery made? **6.** What rules should be observed in the use of a storage battery? **7.** How does a battery hydrometer tell the charged or uncharged condition of the battery? **8.** How much current must the battery be able to supply in order to start the gas engine? **9.** What is the difference between an Edison storage cell and a lead storage cell? **10.** What gases are set free when a storage battery is charged? **11.** What is the cost of an automobile storage battery? How long will the battery last?

226. How to plate articles with copper. Sometimes when one is buying kitchen utensils, table silver, or other metal goods, the dealer says, "This piece is plated, but this piece is solid." For some uses solid ware is preferable, while for other uses plated ware is equally good or better. What is meant by the statement that metal wares are plated, and how is this plating done?

In figure 108 an apparatus for copperplating is shown. A piece of clean carbon from an ordinary dry cell is a convenient article to plate. This is suspended in a solution of copper sulphate from a metal rod connected to the zinc of the battery. The carbon of the battery is connected to a strip of copper. If we permit the current to flow several minutes, a bright coat of copper appears on the carbon. As the current continues to flow the copper gets thicker on the carbon, and the copper plate grows thinner. Then another interesting fact about the chemical effects of electricity appears;

namely, that the copper is taken off the plate attached to the positive terminal of the battery, which plate we shall hereafter call the anode, and is deposited upon the carbon rod where the current leaves the solution, which rod we shall hereafter call the cathode. This is an example of a chemical effect produced by passing electricity through a solution, and it is evident that water may conduct the current if the proper chemical is dissolved in it.

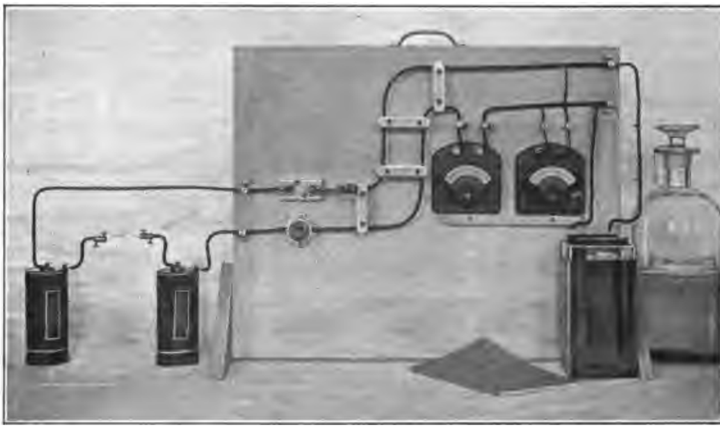


FIG. 108. Materials for studying copperplating

If we change the connections on the plating tank by exchanging the wires on the binding posts, and then close the switch for several minutes, the copperplated cathode will lose a part or all of the copper, and the anode will regain this amount.

In plating it is essential that the solution be of the proper composition and density and that the anode be composed of the metal it is desired to deposit on the objects. The solution must contain a compound of this same metal. The objects to be plated are always attached to the cathode. In this way nickel-plating, brass-plating, zinc-plating, silver-plating,

gold-plating, and platinum-plating may be done. Many of the articles we use in everyday life have been plated with gold, silver, brass, or nickel.

227. The rate of deposit. If a solution of nickel sulphate or zinc sulphate is used in the plating tank, with a nickel anode or a zinc anode in the respective cases, different weights of metal will be deposited when the current flows the same length of time. Michael Faraday first determined these facts with exactness in the year 1834.

The weights of various elements set free in a given time are shown in the table below:

ELEMENT	WHERE SET FREE	SYMBOL	POUNDS DEPOSITED BY 10 AMPERES IN 10 HOURS	GRAMS DEPOSITED BY 1 AMPERE IN 1 HOUR
Copper	Cathode	Cu	.2614	1.186
Aluminum	Cathode	Al	.0742	.337
Gold	Cathode	Au	.5403	2.451
Hydrogen	Cathode	H	.0082	.037
Nickel	Cathode	Ni	.2414	1.095
Silver	Cathode	Ag	.8872	4.025
Tin	Cathode	Sn	.2444	1.109
Zinc	Cathode	Zn	.2687	1.219
Chlorine	Anode	Cl	.2914	1.322
Oxygen	Anode	O	.0657	.2984

To obtain the weight of metal deposited by a certain current in a given time, we need only multiply the strength of the current in amperes by the amount of metal deposited by one ampere in an hour and multiply this product by the time in hours.

So regular is the amount of material deposited under the same conditions that an ampere is often defined as the steady current which will deposit 4.025 grams of silver in one hour from a standard silver-plating solution. As already learned (sect. 218), it can be defined as the current forced through a resistance of one ohm by an electrical pressure of one volt.

228. The lead storage cell and some of its uses. It is quite common in automobiles and other machines to observe electricity in use in appliances which are removed from the generators which supply the energy. This is made possible by the storage cell (fig. 109). If the wires from the two plates shown in the figure are attached to the binding posts which are connected to the battery and the switch is closed, the

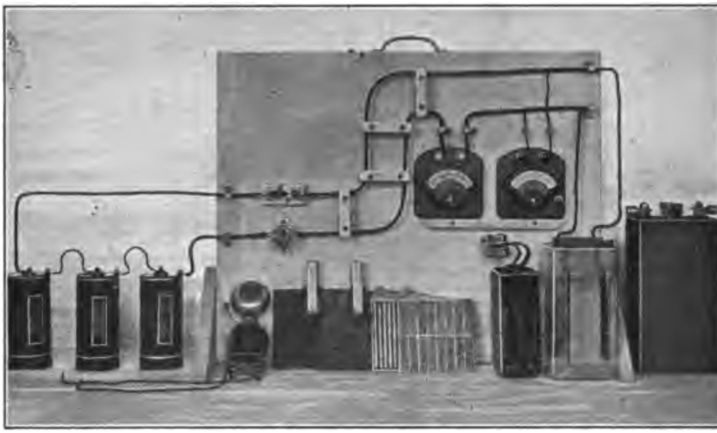


FIG. 109. Materials for studying the lead storage cell

The solution in the cell contains 1 liter of water into which $\frac{1}{8}$ liter of concentrated sulphuric acid has been slowly poured. From left to right the materials shown are three dry cells, an electric bell, two lead peroxide plates, two unused lead plates, a commercial lead storage cell, a laboratory-made lead storage cell connected with wires, and an Edison cell

ammeter shows that a current is passing through the circuit, and bubbles will be seen near the lead plates. This action should be allowed to continue for a minute or more, and then it may be interrupted by opening the switch.

If the dry cells are now disconnected from the binding posts, and an electric bell is inserted in the circuit (care should be taken to reverse the connections on the ammeter and voltmeter), the bell will ring when the switch is closed. Since the two lead plates in the sulphuric acid would not

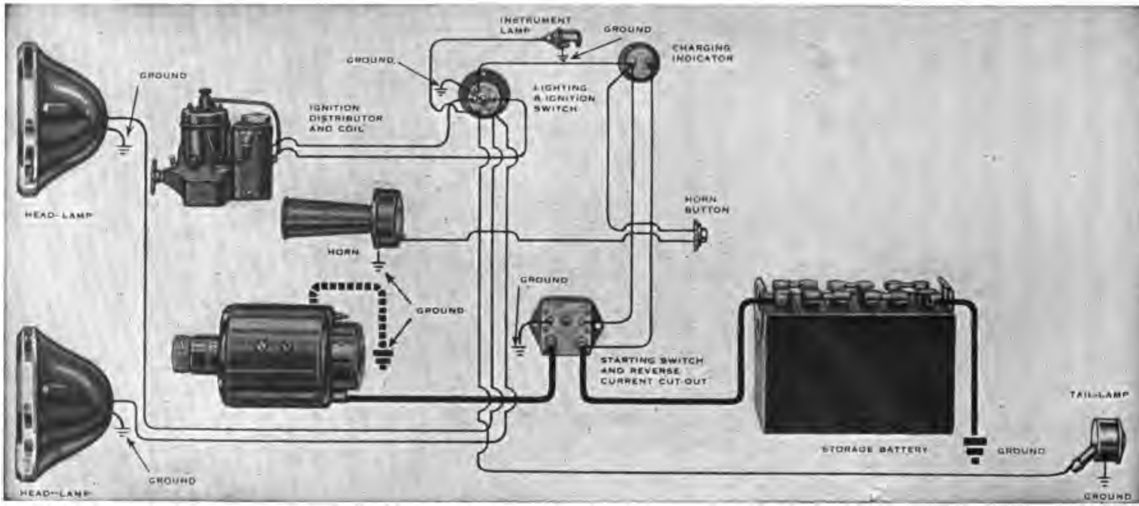


FIG. 110. Automobile electric circuits connected with storage battery

ring the bell originally, a change occurred while the current was passing through the acid solution. Examination will show that one of the plates is now coated with a brown deposit called lead peroxide, a compound of lead and the oxygen which was set free at the plate connected with the positive terminal of the battery.

As the current rings the electric bell the brown deposit may partially disappear, and the two lead plates soon reach such a condition that the bell fails to ring. The cell can be charged again, however, and the entire process repeated.

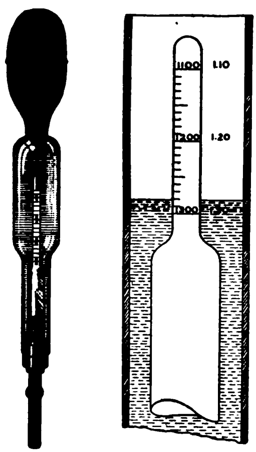


FIG. 111. Hydrometer for testing the acid in storage cells

The hydrometer syringe is so constructed that by its use the specific gravity (density) of the acid may be determined

Electricity is not stored in this cell, however, in the same way that milk is kept in a bottle. As the current flows through the solution the surface of one of the lead plates is changed chemically into lead peroxide. This process is known as charging the battery. It produces the necessary conditions for any electric cell; that is, two unlike plates in a solution that will conduct the electric current. As the current is taken from the cell the lead peroxide disappears, thus discharging the cell. This simple device illustrates the principle of the lead storage cell that has such an extensive use. In the commercial battery two or more cells are used, the plates are closer together, are strongly supported, and differ in other details of construction.

229. The automobile storage battery. The automobile makes constant use of a storage battery. The battery is usually found in a heavily constructed box (fig. 110) in which two or more cells are connected in series. Electric current at voltages depending upon the number of simple

cells in the battery may be obtained to operate the motor which starts the gas engine, or to light the lamps.

Storage batteries are quite expensive and require intelligent care, else they are soon ruined. Owing to their special construction a large current may be taken from them. Their voltage is high, they offer less resistance, and hence they can furnish larger currents. Some automobile-starting motors may require for an instant as much as 250 amperes or more. This is about 500 times the current consumed by the new 60-watt (Mazda B) tungsten lamp. The owner of a storage battery should follow the instructions of the manufacturer concerning its care. The following rules will prove helpful in using the special directions furnished with the battery:

Do not short-circuit the terminals of a storage battery. Do not use an ammeter to test the cells.

The battery should be kept free from dirt and foreign substances, both solid and liquid.

The battery must always be charged with direct current in the right direction.

Keep all connections clean and tight.

Do not bring a flame near the battery during or immediately after charging.

The acid should be kept at the proper height above the top of the plates. Use only pure water, melted ice, or fresh rain water, and handle it in nonmetallic vessels. Do not add acid to the cells.

The battery should be charged at the proper amperage and for the proper length of time.

The condition of the battery is indicated by the specific gravity (density) of the solution, which is determined with a hydrometer syringe.

The acid of one make of battery has a specific gravity (density) of 1.28 to 1.3 when charged, and 1.1 to 1.15 when fully discharged. Other makes may differ. The specific gravity of the sulphuric-acid solution is tested with the hydrometer (fig. 111).

Test the battery each week. If the specific gravity (density) of one cell continues much lower than the others, it may need the attention of a battery expert.

CHAPTER XIX

THE MAGNETIC EFFECTS OF ELECTRIC CURRENTS

230. Questions for Discussion. **1.** How is a compass constructed? How is the mariner's compass constructed? **2.** What kinds of materials are attracted by a magnet? **3.** How are telephone and magneto magnets used? **4.** What kind of a magnet is used in an automobile ammeter? in a battery-testing ammeter? in a watt-hour meter? in a telephone ringer? **5.** Do magnets lose their magnetism? **6.** What is needed to make a magnet that will operate on the current from a dry-cell battery? **7.** Who invented the electromagnet? **8.** What kinds of magnets are used in a telephone receiver? **9.** How is a telegraph sounder made? **10.** How are electric bells connected? **11.** How does an annunciator work? **12.** What are the necessary parts of an electric motor? **13.** How is electricity used in operating street cars? **14.** What kinds of electric circuits are dangerous? **15.** What is the difference between a direct-current motor and an alternating-current motor? **16.** How is a motor started? **17.** Why do most large motors have a "starting box"? **18.** What are the advantages of electric motors? the disadvantages? **19.** What is the difference between a dynamo and a motor? **20.** How are electric currents generated at the power plant? **21.** Why are transformers used? **22.** How is an induction coil made? **23.** How is electricity brought to a residence? **24.** How is a "door opener" made? **25.** How may buildings be protected from lightning? **26.** How is a toy transformer made?

231. Permanent magnets and their uses. If a bar magnet is covered with small nails or iron filings and carefully lifted, most of the adhering metal (fig. 112) will usually, though not always, be near the ends of the magnet. The parts in which the attraction is the strongest are called the magnetic poles.

If a bar magnet is suspended horizontally by a piece of thread at some distance from other magnets and iron, and left undisturbed, it will take a definite position, pointing

approximately north and south. For convenience we call the north end the north pole (N), and the south end the south pole (S). It can easily be shown that like poles of different magnets (two N poles or two S poles) repel each other and that two unlike poles attract each other.

A compass (fig. 112) can be made by magnetizing a steel needle, a safety-razor blade, a small file, or a piece of watch

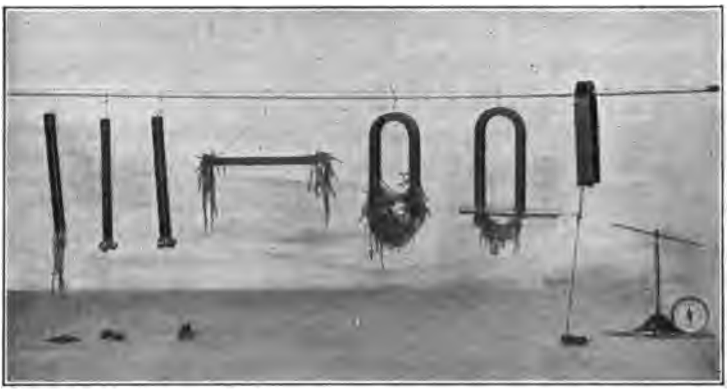


FIG. 112. Demonstration materials for studying permanent magnets

The materials suspended from the rod are three bar magnets to which nails and cobalt and nickel cubes adhere; a horizontal bar magnet with nails adhering at both ends, the whole acting as a compass; two U-magnets with nails, one holding the nails though separated from them by cardboard; a U-magnet holding a nail and piece of wire; two types of compasses

spring. When placed on a floating cork or balanced on a pivot the magnet takes a definite north-and-south direction. This action of the compass is due to the influence of the earth, which acts as though it were a magnet, having a south magnetic pole near the geographical north pole of the earth, and a north magnetic pole near the south pole. The compass needle does not point north and south on all parts of the earth, because the magnetic poles do not coincide exactly with the geographical poles. The compass is used by hunters, sailors, and explorers to determine the directions.

Artificial magnets, such as described above, are made by rubbing steel with a loadstone (leading stone), a mineral with a permanent magnetic quality, or by the use of an electric current. Magnetic tack hammers, telephone magnets, magneto magnets, and toy horseshoe magnets are permanent magnets; the magnet of an electric bell, however, is a temporary magnet, the magnetism of which depends upon the presence of an electric current in a coil of wire about the iron. Permanent magnets gradually lose some of their magnetism, and may be damaged by contact with other magnets, by heating, by mechanical shock (pounding, falling to the floor, etc.), by failure to provide iron keepers for the ends, and by abruptly placing the keeper in position.

232. The region about a magnet. When a horseshoe magnet is dipped in iron filings or small nails (fig. 112), and then removed, the metal usually forms a loop from one pole to the other. When a glass plate is placed over the horseshoe magnet, and fine iron filings are sprinkled evenly over the plate, if it is tapped slightly the filings arrange themselves in definite lines running from the north pole to the south pole of the magnet. Each small piece of iron becomes a tiny magnet and joins its neighbor, forming a connected line of filings. The nails are affected in the same way, but since they are larger, the line formed is irregular.

These lines will always be found in some form near magnets. For convenience they are called lines of force. In some regions the lines will be numerous; in others only a few will be found. Permanent maps of the lines of force can be made by using blue-print paper or paper covered with paraffin. In the latter case the paper must be warmed slightly to "set" the filings. It will be found most interesting to prepare such maps of the lines of force. Scientists, engineers, and electricians find that the pictures of lines of force assist in the understanding of motors, dynamos, electromagnets, and electrical instruments.

233. How a magnet is produced by an electric current. Has magnetism any relation to electricity? How is an electric current used to make a magnet? Suppose that a current of fifteen or twenty amperes is sent through a copper wire and that the conductor is dipped into a pile of iron filings. It is found that when the wire is raised, the bits of filings cling to the copper. No permanent magnet is present, and although copper is usually considered nonmagnetic, the magnetism the wire possesses must be due to the current in it. When the switch is opened, the filings fall from the wire. The current of electricity causes some disturbance in the region about the conductor through which it is flowing, and this outside effect, which is called magnetism, is a very important part of what is known as an electric current. Therefore, to the heating and chemical effects of electricity already discussed we must add its magnetic effects.

234. Magnetism in a coil of wire carrying a current. How can the presence of a direct current in a wire be detected? A horizontal wire through which a current flows is placed parallel to the direction taken by a compass. If the wire with its current is passed about the compass in the manner directed, the *N* pole of the compass is moved as follows:

1. If the current flows in the wire from south to north over the compass, the *N* pole moves to the west.

2. If the current flows down near the *N* pole of the compass, the *N* pole moves to the west.

3. If the current flows from north to south under the compass, the *N* pole moves to the west.

4. If the current flows up near the *S* pole of the compass, the *N* pole moves to the west.

If a loop of wire pointing in the direction taken by the compass is placed around the compass, the needle will move when the switch is closed. Two or more loops will increase the deflection, until the needle reaches a maximum deflection of 90 degrees from the north-south direction. If the current

is reversed in the loop the north pole of the compass will be deflected in the opposite direction. The different positions given above make it possible to find the direction in which a direct current is flowing. Current detectors of this variety can be made also by placing the magnet in a fixed position and arranging a movable coil with a pointer.

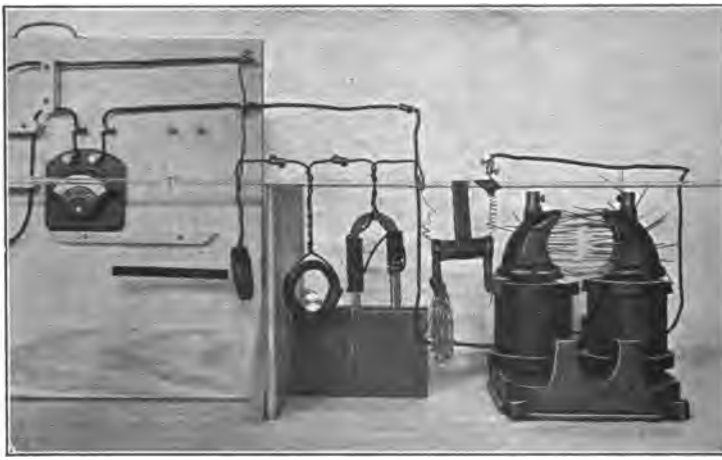


Fig. 113. Demonstration materials for studying electromagnets

The coils are connected in series and carry a current of one ampere. From left to right: bar magnet; three coils of wire wound upon iron cores, the whole serving as magnets (the U-core when wound becomes a relatively strong magnet); the electromagnet of a small motor; the electromagnet of a larger motor or dynamo. The adhering nails indicate the region of magnetic action, or lines of force

That a coil of wire carrying a current is a magnet is further illustrated in figure 113. The bar magnet stands perpendicular to the board when no current flows through the coils, which are connected in series. The instant the switch is closed the magnet swings and takes the position shown, indicating that the coil of copper wire has become a magnet. The compass shows that one side of this coil is an *N* pole and the other an *S* pole. When the circuit through the coil is opened, the bar magnet returns to its original position.

235. Uses of small electromagnets. Electromagnets made by winding insulated wire about an iron core were first made in 1828 by Joseph Henry (1797–1878) of Albany,

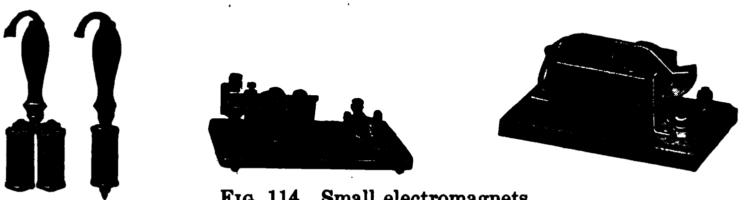


FIG. 114. Small electromagnets

The two at the left are small lifting magnets for experimental work; the middle object shows the electromagnet of a telegraph sounder; at the right is the electromagnet of a toy motor

New York. Many thousands of magnets of this type are now manufactured annually. The range of size is from the tiny coils in a telephone receiver to the giant lifting magnet which handles several tons of iron or steel at one lift.

FIG. 115. Electromagnets of a telephone

At the left is the receiver with its magnets at *H*, fastened to the wires *G*, inclosed in the casing, *F*, and the iron covering plate, *I*; at the right, the magnets and dry cells of the bell ringer

The telegraph sounder (fig. 114) consists of two coils having a resistance of from 4 to 20 ohms. When the iron cores in the coils are magnetized by a direct current from

a battery, the metal bar is pulled down, giving forth a loud click. A spring pulls the bar back into place when the circuit is opened.

The telephone receiver (fig. 115) consists of two permanent bar magnets arranged to form a horseshoe magnet. A soft-iron pole piece is placed on each end. These pole pieces each have a coil of very fine wire (of 30 ohms resistance) about them. The varying current which flows through the small electromagnets strengthens or weakens the permanent magnet, and this causes the iron disk near the ear to vibrate, producing the sound.

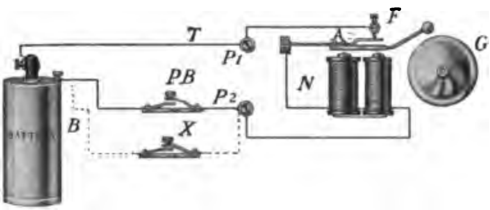


FIG. 116. Electromagnets of an electric bell

B, dry cell; *G*, bell; *PB* and *X*, push buttons at different places, each connecting with the bell ringer, *A*, by means of its own circuit; P_1 and P_2, binding posts; *N*, magnets

The electric bell (fig. 116) consists of two coils of wire forming an electromagnet of the U-type. When the current flows through these coils a piece of metal which is attached to the clapper is suddenly drawn over, thus ringing the bell. The exact operation of any bell and its wiring circuits should be learned by examination and by the construction of a system of electric bells.

Other examples of electromagnets may be found in electric toys (fig. 114), clocks, door openers, annunciators, telephones, arc lamps, motors, automobiles, and street cars.

236. Uses of large electromagnets. Electromagnets of great strength are required in electric motors and generators. The most powerful machines have very large coils, which are usually made of thick copper rods or bars. A single electromagnet of a huge dynamo may have as much as two hundred pounds of copper in the coil, and the dynamo may contain thirty-six such magnets.

The lifting magnet is shown in figure 117. This type is very common in steel mills. It is said that two men can use two similar magnets 62 inches in diameter to unload as much as 4,000,000 pounds of pig iron in ten and one-half hours. Electric engines, street cars, subway trains, and

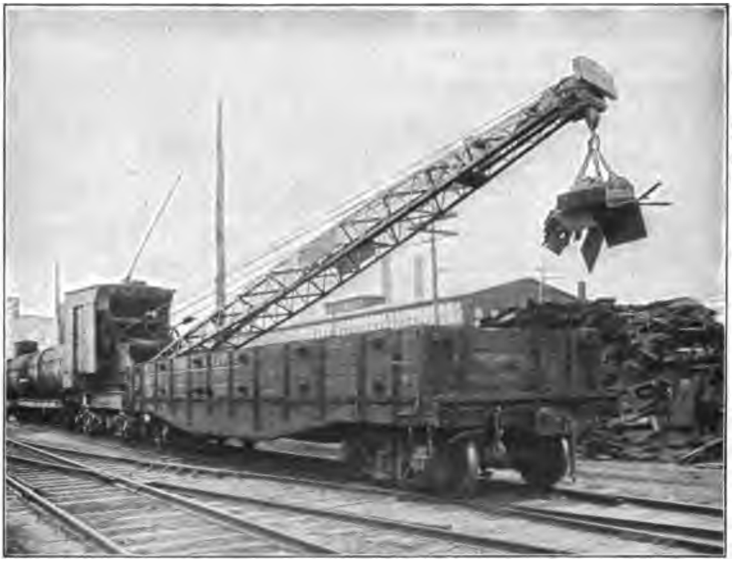


FIG. 117. The lifting electromagnet

Used in lifting heavy iron and steel such as pig iron and steel rails. A magnet thirty-four inches in diameter may be made to lift four tons of solid iron

the electric generators for power plants could not operate without powerful electromagnets.

237. The simple electric motor. The simple electric motor (fig. 118) may be illustrated in two ways: The essential part of the first apparatus is a heavy copper wire that is free to swing between the poles of five U-magnets arranged side by side. The north poles are placed above the wire. When a current of about fifteen amperes is passed through the heavy wire from left to right, the wire quickly swings away from the

reader; when the current in the wire is reversed, the heavy conductor moves toward the reader. The wire moves in each case because a push is developed as a result of the action between the invisible magnetic field of the current in the wire and the lines of force of the U-magnet. This motor is very imperfect, but it illustrates how a machine may be made to change the energy of an electric current into mechanical energy.

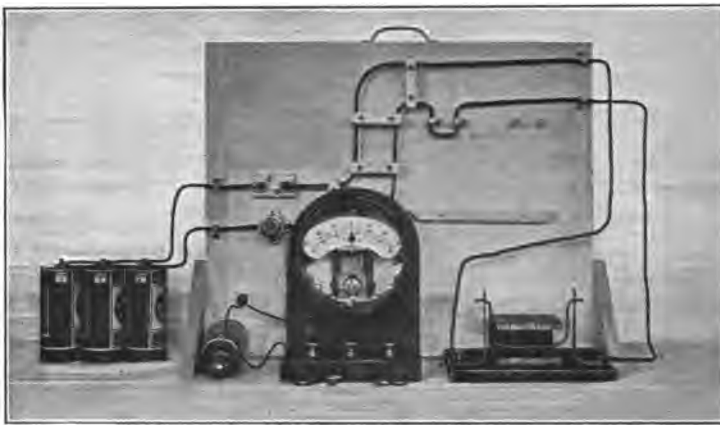


Fig. 118. Demonstration materials for studying the motor

At the right are the parts of the simple motor described in the text. The voltmeter consists of a U-magnet, a coil of wire attached to a pointer, and a graduated scale

Loops of wire can be placed in the magnetic field of the U-magnet, with the coil arranged to rotate in either direction, depending upon the path of the current through the wire.

The voltmeter (or ammeter) also illustrates the motor. The instrument (fig. 118) is made to indicate three different ranges of voltages; namely, 150 volts, 30 volts, and 30 millivolts (a millivolt is $\frac{1}{1000}$ volt). If a dry cell is connected to the 150-volt terminals, the pointer indicates a slight movement of the coil. When the cell is connected to the 30-volt terminals, the motion of the coil is about five times as great,

the pointer showing about 1.5 volts. The direction of rotation can be reversed by exchanging the wires on the terminals of the cell.

The movable coil carries a small current and swings about an iron core. The coil therefore has all the properties of a magnet, with a north pole on one side and a south pole on the other. The motion, then, is due to the action between the magnetic poles of the coil and the poles of the permanent magnet. A spring is used to bring the coil to its original position. Many common electrical devices for measuring electric currents are merely modifications of the simple motor.

238. Danger of electrical injuries. If precaution is taken not to connect the dry cell directly to the 30-millivolt scale, which would burn out the coil, an additional experiment of interest may be shown. The human body has a very high resistance, from 1000 to 10,000 ohms or more, depending largely upon the condition of the skin. According to Ohm's law (sect. 218) a dry cell (1.5 volts) ought to force about one thousandth of an ampere through a resistance of 1500 ohms. The circuit of the millivolt meter is designed to carry only a few hundredths of an ampere, and the pointer will register the small current which flows through the body when the hands grasp the terminals at the bottom of the voltmeter. If the fingers are wet, thus reducing the resistance, the pointer indicates that more current passes. A still greater current is forced through the body when the hands are wet with salt water. A current of about ten amperes is used in the electrocution of criminals. As low an amount as one-tenth ampere may be dangerous under certain conditions. Workmen regard from 400 to 600 volts as sufficiently high pressure to force enough current through the body to be fatal. Cases are recorded in which the 110-volt lighting circuit proved dangerous. Many small motors operate upon 110- and 220-volt circuits. Street-car and subway motors usually use a 600-volt circuit.

239. The essential parts of a motor. What changes can be made in the simple motor described above so as to construct a working machine? This question can be answered by a study of the motor shown in figure 119. The electromagnet is turned aside so that the bar magnets can be brought into

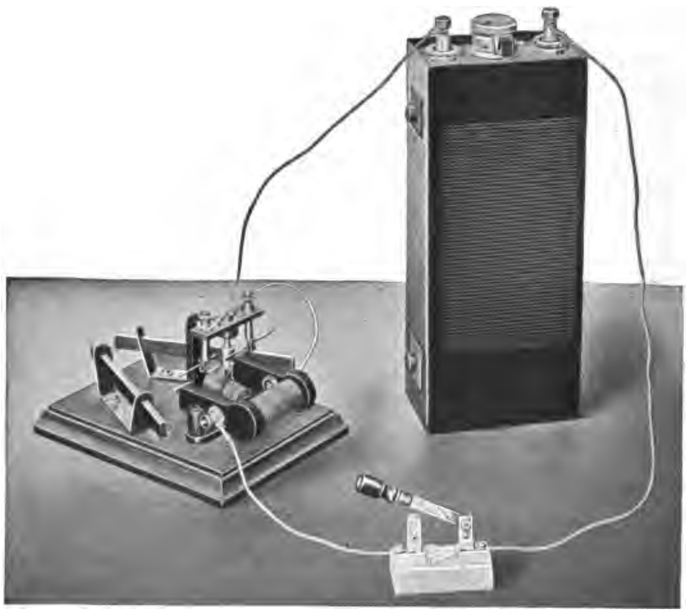


FIG. 119. A small motor

This motor is operated by an Edison storage cell

place on either side of the vertical axle. The bar magnets furnish the magnetic field. A coil of wire mounted on an iron core is placed on the central shaft that can be rotated. The ends of the coil are connected to a metal cylinder standing just above the coil. When the terminals of a single dry cell are attached, the current can pass through the metal brushes to the coil. When the switch is closed, the coil spins quite rapidly. The motor fails to operate, however, when two

N poles or two S poles are used near the rotating coil. Why? The necessary parts of a direct current motor are a suitable magnetic field, a coil for rotation (usually called the armature), and a device (usually called the commutator) to send the current into the armature at the proper instant and in the correct direction.

240. Different kinds of motors. Permanent magnets are not adapted for use in motors. A modification must be made in order that the magnetic field may be furnished by a stronger electromagnet, as is done in all practical motors. In figure 119 the bar magnets have been swung outward from the magnet. A coil of wire wound upon a suitable iron frame is placed near the armature. The motor may now be operated: first, by using a different source of current for the armature and electromagnetic field; second, by connecting the armature and field (the terminals of the coil) in series with a source of current; and third, by arranging the armature and field circuit in parallel (shunt) with a common source of current.

The first method is not suitable for practical motors; the second illustrates the series motor, which is used in electric vehicles and at times on street cars; and the third represents the so-called "shunt" motor, which has extensive use. An additional type of direct-current motor, called the compound motor, is a combination of the series and the shunt motor. In addition to the direct-current motors there are several different types of machines that are designed to operate upon an alternating-current circuit.

241. Domestic and commercial uses of motors. Electricity provides the most convenient means of transmitting and using energy. The electric motor may have perfect control, reliability of operation, range of distribution, cleanliness, and less danger of accidents than other sources of energy. Motors are used in the home to operate washing-machines, vacuum cleaners, meat choppers, ice machines, fans, elevators, pumps, and ice-cream freezers.

There is almost no limit to the industrial uses of motors. Electric vehicles, printing presses, lathes, cranes, dental appliances, air compressors, coal cutters, band saws, shoemaking machinery, tool grinders, and automobile and farm machinery may be named as illustrations.

242. Electric bells in a modern city residence. If a residence is supplied with alternating current both day and night, the electric bells can be operated with a small device

FIG. 120. Demonstration materials for studying the transformer

At the left, a bell-ringing transformer for an alternating current circuit; in the middle, the parts of two transformers; at the right, an ordinary commercial transformer used outside of houses for reducing electric currents for house use

called a bell-ringing transformer. This, when once installed, will last many years, requires no repairs, and costs practically nothing for operation. How does this appliance work? Two wires are brought from the alternating-current circuit (110 volts) to the terminals on the left (fig. 120) of the transformer. The bell circuit is attached to the binding posts on the right side of the transformer. The bell rings vigorously. However, the full current from the 110-volt circuit does not enter the magnets of the bell.

It is a peculiar fact that in this case a current is obtained from a coil which has no direct connection with a source of

electricity. The voltage on the first circuit is 110 volts, that on the second is about 11 volts. This information gives us a hint for naming the device a transformer. The voltage is transformed, "stepped down," or "changed over" from 110 volts to 11 volts.

243. Uses of the transformer. A full explanation of the transformer by means of which the reduced voltage is secured must be reserved for the later course in physics. However, we may say that as the current alternates 120 times (60 complete changes) per second in the 110-volt coil, the reversals of the current cause the lines of magnetic force to swing back and forth through the 11-volt coil, causing an alternating induced current to pass through the coil and its circuit. The core of steel concentrates the lines of force about the coils. The transformer, then, is a device which makes use of the magnetic field about an electromagnet.

Large transformers are used to distribute the electric currents to the community. Such transformers are commonly seen fastened to posts in streets and alleys. Two terminals of the high-voltage coil of relatively small wire are shown (fig. 120). The low-voltage coil is wound in two sections, giving four terminals as shown on the front of the case in the figure. These coils can be connected so as to give 110 or 220 volts. The wires of the secondary coils (110–220 volts) are larger than those in the primary coils (1100–2200 volts), and this indicates that heavier currents pass through them. The transformer is merely a device for trading volts for amperes, or vice versa; that is, when the voltage is high the current will be low, when the current is large the voltage will be small.

There are many different styles of transformers adapted for domestic and commercial use. They range in size from the small bell-ringing transformers to the huge transmission transformers housed in large power plants. There are distributing transformers of all sizes, sign-lighting transformers,

instrument transformers, spark coils, induction coils, motor-starting transformers, etc. — the list is almost without end.

244. The supplying of energy to the home. How does the transformer enable the dynamo to supply energy for lamps, heating devices, and motors? Three important facts should be kept in mind: first, electricity is not consumed in the home, as is coal or gas, but returns to the generator; second, electricity, like moving water, is only a means of transferring energy, and the power company sells the energy possessed by the moving electricity; third, a transformer such as we have described is used only on an alternating-current circuit.

The direct-current power plant is used chiefly where the energy is not transferred to a great distance, as in rural communities, villages, homes, and stores, and often in cities for hotels, schools, and factories. The rural plant usually consists of a small direct-current generator having a capacity of about 1000 watts at 32 to 40 volts, a storage battery consisting of from 16 to 20 cells connected in series, a switchboard for the instruments, fuses, etc., and a gasoline engine to drive the generator. The larger direct-current generators used in factories and sometimes for the central power stations in small towns operate at from 250 to 300 volts or more. The current is obtained direct from the generator mains, which usually consist of large, expensive copper cables.

245. Use of direct and alternating currents. It is greatly to the disadvantage of the direct-current system that large conductors are required. The energy transmitted is determined by the current and the voltage. The number of watts will be equal to the product of the amperes and the volts; hence, when the voltage is low, as it must be in a machine having a commutator, the current must be high in order to transmit a definite number of kilowatts. The heat losses in a wire increase with the square of the current; that is, to double the current makes the heating effect four times as great. The difficulty is solved, however, if the voltage is increased

and the current decreased, but this is impossible with the direct-current system. Therefore, when very large voltage is required, the alternating-current generator is used, and by

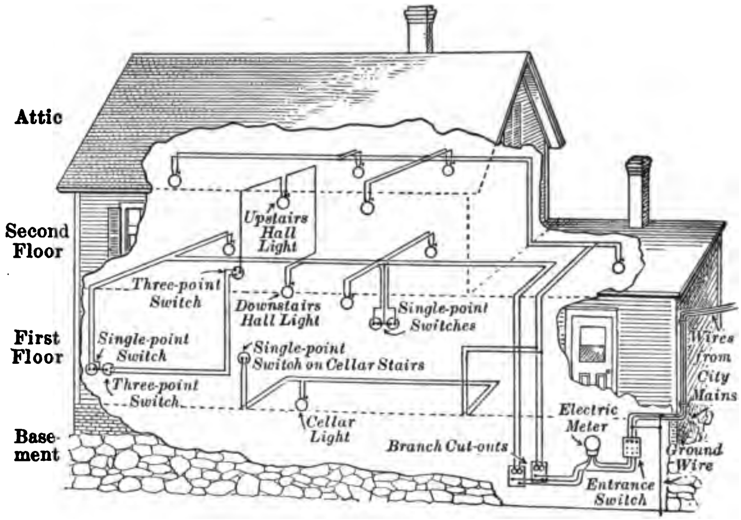


FIG. 121. The wiring circuits of a dwelling house

means of it energy can be transmitted at high voltage with low current strength. A table will show the economy of this method for the transmission of power.

TABLE SHOWING THE ADVANTAGE OF TRANSMITTING A SMALL CURRENT AT HIGH VOLTAGE RATHER THAN A LARGE CURRENT AT LOW VOLTAGE (LINE RESISTANCE, 3 OHMS)

VOLTS	AMPERES IN CIRCUIT	HEAT LOSSES IN LINE IN WATTS	WATTS TRANSMITTED TO A MOTOR	EFFICIENCY PER CENT
300	100	30,000	0	0.
400	75	16,875	13,125	43.8
500	60	10,800	19,200	63.3
800	37.5	4,220	25,780	85.9
1000	30	2,700	27,300	91.0
2000	15	675	29,325	97.8

In the alternating-current system a generator consisting of a huge armature, driven by steam, gas, or water power, rotates in the magnetic field produced by electromagnets. The voltage produced by this dynamo is raised to a higher voltage by means of "step-up" transformers. The energy is transmitted several miles with small losses, and then by

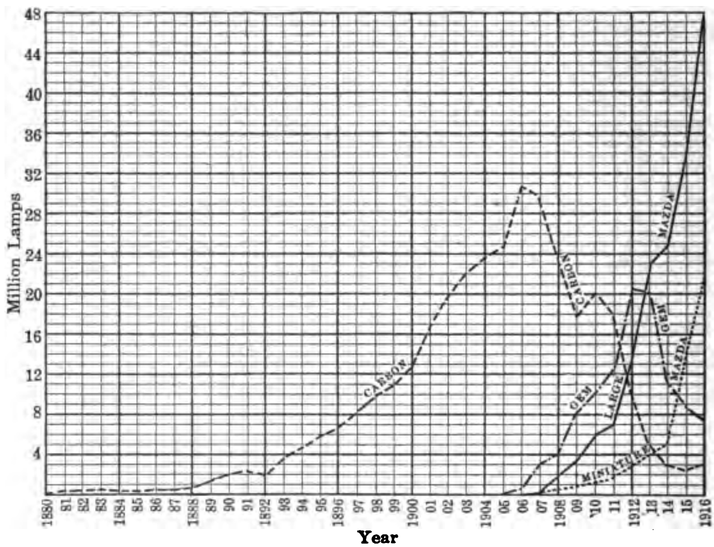


FIG. 122. Use of incandescent lamps

The number of incandescent lamps of different kinds sold yearly from 1880 to 1916 is an interesting comment upon the different stages in the development of the lighting industry

means of "step-down" transformers it is made available for use. Smaller distributing transformers, such as are in most common use, receive the current at 1100 or 2200 volts and reduce it to 110 or 220 volts, which is a safe voltage for community use.

Wires from the low-voltage coils of the distributing transformers are brought to the basement of the residence, where suitable fuses and switches are installed. The watt-hour

meter is then inserted in the circuit, and the electricity is finally available in the rooms of the residence, as shown in figure 121.

246. Electrical industries. It has been estimated that about 70 per cent of the whole population — that is, over 70,000,000 people — use electricity in some way every day. The following table of estimates indicates the extent to which these industries constitute a source of national wealth as compared with other industries:

	Value	Year	Rank
Agricultural products[1]	$6,800,000,000	1916	1
Export trade	5,400,000,000	1916	2
Railroads (gross receipts)	3,600,000,000	1916	3
Textiles	3,414,615,000	1914	4
Iron and steel products	3,223,144,000	1914	5
Electrical industries	2,825,000,000	1917	6

The values for the various branches of the electrical industry for the year 1917 are approximately as follows:

Electric railways	$800,000,000
Electric manufacturing	600,000,000
Power plants	550,000,000
Telephony	425,000,000
Telegraphy	175,000,000
Miscellaneous	275,000,000
Total	$2,825,000,000

Electrical industries produce thousands of articles, but the chief ones are dynamos, transformers, switchboards, motors, storage and other batteries, arc lights, searchlights, incandescent lamps (fig. 122), lighting fixtures, telegraph apparatus, telephones, insulated wire, annunciators, electric clocks, fuses, rheostats, heating and cooking apparatus, measuring instruments, magneto and automobile apparatus.

[1] Timbie, W. H., Elements of Electricity.

Few aspects of modern science have undergone more rapid development in recent years than has electricity. It has come to be a part of the daily life of almost every man and woman. It opens many new opportunities for industrial, professional, and inventive genius. It engages the casual attention of the child at play, and provides baffling problems for the most highly trained men. Although enormous development of electrical industries has occurred, and although we use electricity so constantly, our knowledge of the real nature of electricity itself is probably just in its infancy.

PART IV. THE EARTH IN RELATION TO OTHER ASTRONOMICAL BODIES

CHAPTER XX

THE MOON, PLANETS, AND COMETS

247. Questions for Discussion. **1.** Does the moon shine by its own light? Does the sun? Does the earth? **2.** What causes the water to rise from oceans and lakes, thus maintaining the supply which flows down again and provides water power? **3.** What is the source of the energy held in the fuel from which heat and electricity may be produced? **4.** Is the sun the source of all our energy? **5.** Is the sun the source of energy for all the stars and planets? **6.** Why does the moon change its appearance from evening to evening? **7.** What causes the change of seasons on the earth? **8.** Is the moonlight which comes to us from the moon or from the sun? **9.** Since both earth and moon revolve about the sun, how do you account for the fact that the moon is sometimes visible from the earth and sometimes not? **10.** How could you make a simple telescope so as to study the moon? **11.** What are the reasons for thinking that the moon is not inhabited and does not produce crops of plants as does the earth? **12.** What is an eclipse of the moon? **13.** What arguments are presented to show that Mars is inhabited?

248. Introductory statement. In Part III we discussed the use of energy upon the earth, and the sun as our source of radiant energy. It will be profitable at this point to consider the relation of the earth to the sun, moon, stars, and planets. We may gain a notion of the relative insignificance of the size of the earth and of the men who live upon it. Notwithstanding our smallness as parts of the universe, we have a right to dignify ourselves by recalling that it is

by means of our intellects that we may know something of this vast universe. One astronomer[1] has said:

> If the human mind sometimes seems to have wings, by the aid of which it conquers stellar space; if man by his intellectual courage lifts himself to sublime heights — it must also be borne in mind that he is really a very small atom in nature's colossal work. We feel our infinite littleness when contemplating the wonder of a starry night, above all; for we know that these are not mere points of light that we see twinkling in the vast dome of the sky — they are suns, huge incandescent globes, gigantic foci of light, centers of systems of worlds! We know, too, that those distant stars resemble the star which illuminates our own world, and that in the vastness of space our sun is but a star.

249. Phases of the moon. Every thoughtful person has looked at the moon in wonder and has noted its apparent change of shape during the month. Each month when it is a "new moon" it seems to be a thin crescent, with the tips turned toward the east (fig. 123). A few days later it has the form of a semicircle, and in another week it appears to be perfectly round. Then it gradually changes in the reverse order to the semicircle and to the thin crescent, with the tips now turned toward the west. Primitive peoples noted the regularity of these changes and measured their time by them, the American Indians saying that in so many moons this or that religious festival or other occurrence would take place.

The moon is not a light-giving body except in the sense that it reflects light which shines upon it from the sun. It moves around the earth and is carried with the earth around the sun. Its changing positions relative to the earth and sun cause its changing appearances, which we call its phases.

250. Amount of light from the moon. It sometimes seems that the amount of light received from the moon is very great and that it may be a considerable fraction of that

[1] Flammarion, Camille, Astronomy, pp. 128, 129.

which is received from the sun. This conclusion is quite erroneous, for the brightest full-moon light is only about $\frac{1}{500000}$ of the brightness of sunlight. Taking the whole month into consideration, the amount of light and heat received from the sun is about 2,500,000 times the amount received from the moon; or, in other words, the earth receives as much light and heat from the sun in thirteen seconds as it receives from the moon during a whole year. It follows from this that it is not reasonable to suppose that the moon has any important climatic effects on the earth. This conclusion is confirmed by observations which have been made by the weather bureaus of various countries for many years. It is found from the records that there is no certain relationship between the phases of the moon and the characteristics of the weather.

FIG. 123. New moon

The moon in its second day, also the old moon in dim outline. Photograph by the Yerkes Observatory

251. Distance and size of the moon. It is commonly supposed that it is impossible to measure with certainty the distances to the heavenly bodies and that what astronomers say about them is merely speculation. This opinion is erroneous, for these distances are measured in the same sense that distances are measured on the surface of the earth, and the percentage of error is very small except for the stars. The essence of the method of measurement is very easy to understand. It depends upon the fact that the moon appears in

different directions when seen from different points on the earth's surface. By means of exact measurements of the distance between two points of observation, and of the two angles of observation, the distance to the point of the third angle may be accurately calculated.

After the distance of the moon has been found, its size can be determined. The computations show that its diameter is 2163 miles, or approximately $\frac{1}{4}$ of that of the earth. Its volume is about $\frac{1}{60}$ of that of the earth, while its mass is nearly $\frac{1}{80}$ of that of the earth.

252. Atmosphere and water on the moon. The moon differs from the earth in the very important point that it has no atmosphere surrounding it. This is shown by the fact that the illuminated part of its surface is always seen undimmed by clouds or even an atmosphere. The reason that the moon has no atmosphere is that its attraction is not great enough to hold one in its vicinity. An atmosphere such as that which surrounds the earth is made up of an exceedingly great number of small masses called molecules, which we have already considered. Their incessant pounding on every object in our air produces what we call the atmospheric pressure, which at sea level is about fifteen pounds per square inch.

There is no water upon the moon's surface. When observed through powerful telescopes all that side of the moon which is toward the earth is seen to be simply a rocky and desolate waste. It has sometimes been supposed that on the side of the moon which is never turned toward the earth there might be water and conditions like those which make the earth habitable; but this is impossible, for if there were an atmosphere on the other side it would quickly spread all over, and part of it would appear on the side of the moon toward the earth. If there were water on the other side and no atmosphere, at least a part of the water would be evaporated and would produce an atmosphere of water vapor, part of which would pass to the side toward the earth.

253. Erosion and craters. In consequence of the fact that the surface of the moon has neither atmosphere nor water, it has suffered no erosion. It is not known that rains and snows have ever dissolved the rocks or that winds have ever scattered their disintegrated remains in the valleys. How different it has been upon the earth! On its surface rocks have crumbled away, and mountains have actually disappeared in the course of geological time as a result of the disintegrating effects of water and the atmosphere. The records of the early condition of the earth's surface have been destroyed by the wasting effects of air and water. On the other hand, on the surface of the moon there are preserved for our inspection through the great telescopes of modern times the records of the forces which broke up and scattered about in wild disorder materials of the surfaces of worlds in their early stages. Its surface is covered with great circular pits called craters (fig. 124), some of which

FIG. 124. The moon at six days

Photograph by the Yerkes Observatory

are as much as a hundred miles in diameter and two or three miles deep. There are also mountains of spirelike character and of great height.

The explanation of the lunar craters is not a simple matter, and astronomers are not entirely in agreement on the question. Their great size, the absence of any water on the surface of the moon, and the absence of distinct lava flows make it doubtful whether they are closely analogous to the volcanic craters which are now found on the surface of the earth. It has been suggested that they have been depressed by impacts of great meteorites from the outside, but this is not supported by adequate evidence. The moon seems to have preserved for us, because of its lack of an atmosphere and a water covering, a record of what the earth probably went through at an early stage of its development.

254. Climate of the moon. The moon revolves around the earth, and the earth and moon revolve around the sun at a distance four hundred times their distance from one another. Consequently the average distance of the moon from the sun is about the same as that of the earth, and, other things being equal, its climate would be about the same as that of the earth. There are two important factors, however, which make it entirely different. The first of these is that it turns on its axis very slowly; in fact, it rotates in such a way that the same face of it is always turned toward the earth, and its day is twenty-nine and one half of our days. If there were no other difference, the daily change in temperature would be enormously greater than on the earth. If the earth's day were equal to that of the moon, the temperature would probably fall below the freezing point every night, even at the equator, and it would ascend to unusual heights during the day.

The second reason why the climatic changes of the moon are different from those of the earth is that it has no atmospheric covering. The sun's rays are never cut off by clouds

or even diminished by the partial screen of an atmosphere, and consequently the temperature rises very high in the long interval between sunrise and sunset, which is nearly fifteen of our days. After the sun is set, the other extreme of temperature soon begins to develop. There is no atmosphere to hold in the heat which has been accumulated during the day. The temperature falls in the course of two or three hours from a maximum reached in the daytime, which is supposed to be near the boiling point, down to what is probably near freezing point. In the course of one of our days it descends probably very far below our zero and remains there the rest of the night.

As a further consequence of the absence of both water and atmosphere on the moon, and of the extremes of temperature, it follows there can be no life upon it. It is believed by astronomers that the conditions on the moon have never been essentially more favorable for life than they are at present, and that they will not become more favorable in the future unless in some way its mass increases so that it may hold an atmosphere around it by the power of its gravitation. The moon is a dead world, which has pursued its course around the earth and, with the earth, has revolved around the sun through long ages. It illuminates the earth part of the time with its feeble rays and produces the tides, which rush in and out twice a day upon the shores of the oceans.

255. Eclipses. The earth casts a shadow, which extends, of course, in the direction opposite to the sun. When the moon passes into this shadow it is eclipsed, for then the direct light of the sun is cut off. The moon would be eclipsed every month at full moon if its orbit were not somewhat inclined to that of the earth so that ordinarily it passes above or below the earth's shadow.

The moon too casts a shadow, which now and then strikes on the earth and produces, in a limited region, an

eclipse of the sun. For persons in the path of the shadow the sun's light is cut off (fig. 125), and for a short time, usually only a minute or two, the sun is invisible.

The accuracy with which astronomers know the distance, dimensions, and motions of the moon is shown by the fact that they are able to predict with a high degree of accuracy

FIG. 125. The sun at total eclipse

The picture shows the crown, or corona, around the sun. Photograph by the Yerkes Observatory

when eclipses will occur. It can be determined when an eclipse will occur and from what points on the earth's surface it will be visible. Computations of eclipses are made many years in advance, and astronomers organize and equip expeditions at great expense to go to favorable places for observing them.

Eclipses of the sun have been used in the most interesting manner to locate in our system of counting time some of the

dates of ancient history. In certain cases writers have mentioned facts occurring many centuries ago, before our present system of counting time was in use, and have stated that certain events occurred at the time of a total eclipse of the sun in a definite place on the earth's surface. The dates of these eclipses have been determined by astronomers by counting back across the centuries for more than two thousand years; and thus in our system of counting time the dates of events which were given in some other system have been determined for historians.

256. Planets which revolve about the sun. Next to the moon the planets are most readily observed. The eight planets, of which the earth is one, revolve about the sun. They are observed by means of light reflected from the sun instead of by means of their own light as is true of the sun and other stars. It was supposed by the ancients that the apparent motion of the sun was due to the actual revolution of the sun around the earth. To most of them it was inconceivable that any other body could be enormously greater than the earth and that the earth should revolve around it. But with the improvement of astronomical instruments and methods it has been found that the earth revolves around the sun in a path which is almost circular.

The seven other planets which revolve around the sun move in the same direction as the earth and almost in the same plane. It is difficult to represent the orbits of all the planets on the same scale on the page of the book, because those which are farthest from the sun are at such a great distance compared to those which are nearest. Their names, their proportionate size as shown by diameters, their distances from the sun, their periods of revolution around the sun (their years), and their periods of rotation (their days) are shown in fig. 126 and in the table on page 253.

It is seen from the table that those planets which are near the sun complete their journey around it in a very

short time. If one were living on the planet Mercury and counted his age in terms of its years, he would be four times as old as he would be if he were living on the earth. If people lived there and their activities were divided up as ours are, instead of a year of school being about one hundred and eighty days long, as it is on the earth, it would be only forty days, or

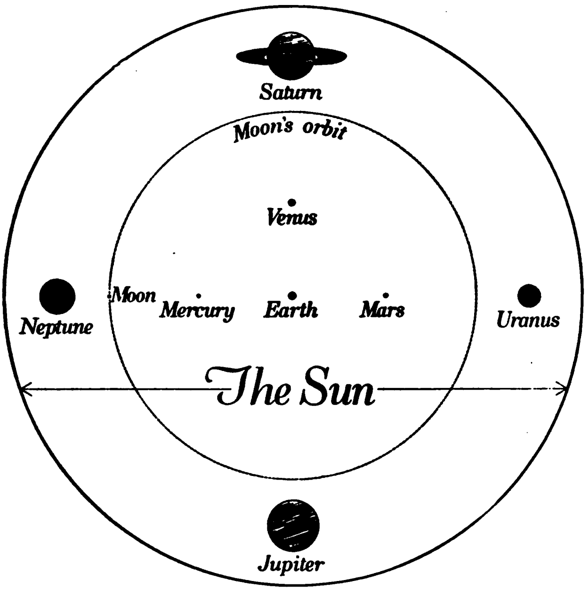


Fig. 126. Diagram of relative sizes of the sun and planets

about one and one third of our months. Since the length of the day of Mercury is unknown, the number of days there might be quite different from the numbers given. On the other hand, the remote planets move in such large orbits and so slowly that immense intervals of time are required for them to make their journey around the sun. In terms of the year of Neptune we should all still be very young. These calculations and others which you can make should help to give an understanding of the periods of revolution and of rotation of the planets.

IMPORTANT FACTS CONCERNING THE PLANETS

PLANET	DIAMETER	DISTANCE FROM THE SUN	YEAR	DAY
Mercury . .	2,765 mi.	36,000,000 mi.	3 mo.	?
Venus . . .	7,726 mi.	67,200,000 mi.	7 mo.	?
Earth . . .	7,913 mi.	92,900,000 mi.	12 mo.	24 hr.
Mars . . .	4,312 mi.	141,500,000 mi.	23 mo.	24 hr. 37 min.
Jupiter . .	84,570 mi.	483,300,000 mi.	12 yr.	9 hr. 55 min.
Saturn . .	69,780 mi.	886,000,000 mi.	29.5 yr.	10 hr. 14 min.
Uranus . .	31,900 mi.	1,781,900,000 mi.	84 yr.	?
Neptune . .	34,900 mi.	2,791,600,000 mi.	165 yr.	?

NOTE. The moon (not a planet) has a diameter of 2163 miles. The sun (a star) has a diameter of 866,540 miles.

257. Mercury and Venus. The planets nearest the sun are Mercury and Venus. The diameter of Mercury is a little less than 3000 miles and, like the moon, its mass is so small that it cannot retain an atmosphere. Since it is much nearer the sun than the earth, it gets proportionately more light and heat — in fact nearly seven times as much per unit of area as we receive. This fact, associated with the fact that it has no atmosphere, means that the day side of Mercury is intensely heated. Some vague markings which have been observed upon its surface seem to indicate that it always presents the same face toward the sun, just as the moon always presents the same face toward the earth. If this is true one of its sides is perpetually burned by the intense rays of the sun, while the other is in perpetual night and, consequently, very cold.

The planet Venus has a diameter of a little more than 7700 miles and is therefore nearly as large as the earth. Observations show that it has an atmosphere comparable in amount to that which surrounds the earth; for example, when Venus passes between the sun and the earth it is seen to be surrounded by an atmospheric ring which is illuminated by the rays of the sun. Venus is in many respects similar to the earth, and the possibility of its being inhabited by

creatures analogous to those on the earth is greater than in the case of any other planet. Its year is only a little more than half that of the earth, while it receives per unit area about twice as much light and heat from the sun as does the earth. The length of its day is not known, but if it is approximately the same as that of the earth the conditions on Venus are in a general way similar to those on the earth, the chief difference being that the seasons are shorter, while the climate is considerably warmer. In fact, if the earth were at the distance of Venus its average temperature would be 150° F. instead of 60°, as it is at present.

Venus is the most conspicuous object in the heavens besides the sun and moon. When it is at its greatest brilliancy, as evening or morning star, it gives enough light to make buildings cast perceptible shadows. It is not always visible; for when it passes between the earth and the sun or around to the part of its orbit opposite the sun, it is obscured, or lost in the sun's more brilliant rays. Venus was an evening star in the late autumn of 1917, and will be thereafter at intervals of one year and seven months. Its appearance as morning star is intermediate between its appearances as evening star.

258. The red planet Mars. The best known of all the planets is Mars. The reason for this is that it is relatively near the earth and well situated for observation, and also that it has a thin atmosphere, which permits us to obtain good views of its surface. The diameter of the planet is about 4000 miles, or one half that of the earth. Conspicuous markings on its surface have been recorded for about two hundred years, and it has been found by watching them that the day of the planet is only a little longer than that of the earth. Its axis of rotation, too, is inclined to the plane of its orbit about the same as the axis of the earth is inclined to the plane of its orbit. Consequently the day and night and seasons of Mars are much like those of the earth except that the seasons are twice as long. The principal difference is due

to the fact that Mars is farther from the sun and receives per unit area only 44 per cent as much light and heat from the sun as are received by the earth.

The general surface of Mars is described as a dull brick red. There are on it, however, large irregular areas (fig. 127) that have a brownish and sometimes a greenish cast. There is certainly no large body of water upon the planet, and consequently the climatic conditions must be very different from

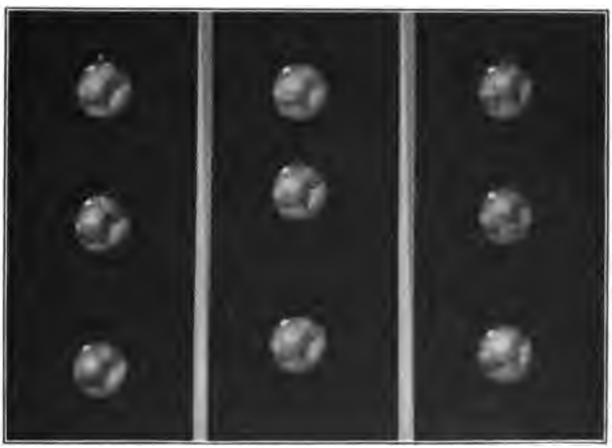


FIG. 127. Mars

A series of photographs by which the rotation of Mars is shown. Only a few seconds intervened between the three photographs of each vertical row. An hour and twenty-two minutes intervened between the upper left-hand and the lower right-hand photograph. Photographs by the Yerkes Observatory

those of the earth. It is extremely probable that there is some water on Mars, for during a winter of one of its hemispheres there appears around its pole a white mantle or cap, often covering an area approximately as large as the United States. This white mantle generally appears rather quickly; that is, in the course of two or three days. It remains during the long winter of Mars, and as spring approaches and "the sun mounts daily higher in its sky,"

the polar cap gradually disappears. The fact that the snow disappears from the poles of Mars as the spring approaches means in the first place that it is probably thin, and in the second place that the atmosphere above it is probably dry so that the process of evaporation takes place.

259. The "canals" upon Mars. Interest in Mars received a great stimulus in 1877 by the discovery of markings upon it by an Italian astronomer, Schiaparelli. The markings which he observed appeared to be very long and straight and narrow. He called them *canali*, which unfortunately was translated into English as *canals*. This led some people to the conclusion that upon the surface of Mars there is an immense network of irrigation ditches, which, of course, could only have been made if the planet were inhabited by highly intelligent beings.

The American astronomer Lowell was also convinced of the reality of the markings. He said that the markings are about 20 miles wide and from a few hundred miles to 3500 miles long. He thought they are not canals, but streaks of vegetation which grow along the banks of irrigating ditches. He suggested that along the middle of one of the so-called canals there is an irrigation ditch or canal with smaller ditches leading off to the sides, which together irrigate a tract of country from 20 to 50 miles in width and as long as the canal. This interpretation also implies the existence of highly intelligent creatures on the planet.

The conclusions of Lowell have not obtained very wide acceptance among astronomers because, in the first place, the observational data are uncertain, and in the second place, the interpretation of them involves serious difficulties which as yet have not been removed. There are upon Mars conditions of temperature and moisture which would seem to us to make intelligent life impossible.

260. Jupiter. Jupiter is the greatest of all the planets and is in volume more than one thousand times as large as the earth. It has no fixed markings upon its surface, but there

are great clouds, sometimes one thousand miles across, which develop and disappear in rapid succession (fig. 128). It seems perfectly certain, in view of its primitive condition as well as of its great distance from the sun, that no life can exist upon its surface.

An interesting consequence of Jupiter's great dimensions and rapid rotation (its day is nine hours and fifty-five minutes) is that it is very much bulged at the equator and flattened at the poles. Its elliptical form and the belts across its surface can be observed by means of telescopes a few inches in diameter.

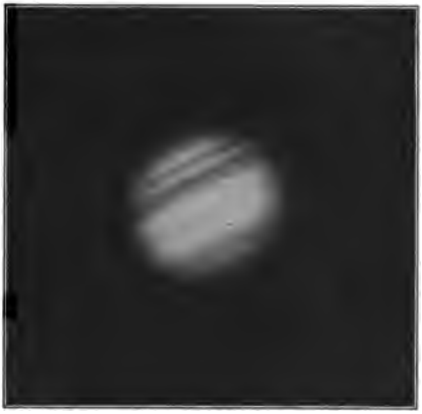


FIG. 128. Jupiter

Note the cloudlike bands which appear upon this planet. Photograph by the Yerkes Observatory

As might perhaps be expected, Jupiter has a large number of moons. The first four were discovered by Galileo in 1610 with the first telescope used by man to record the facts regarding the heavens. These four moons were in fact the first heavenly bodies discovered with the aid of an instrument. The fifth satellite of Jupiter was discovered in 1892, and since then five other small moons have been found. The largest ones are larger than the planet Mercury, and the smallest ones are less than one hundred miles in diameter. The eight which are nearest the planet revolve around it from west to east, which is the direction in which the planet rotates, but the two most remote revolve in the opposite direction.

The planet Jupiter was visible as a conspicuous object in the eastern sky in the late autumn of 1917; it will be visible

in the eastern sky at intervals of one year and one month thereafter, and in the western sky at intermediate periods. It can be distinguished from the stars by the fact that it is more brilliant than any fixed star and shines with a steadier light, and a few nights' observation will show that it is moving among the stars.

261. Saturn. The planet Saturn is a little smaller and somewhat less dense than Jupiter. It has nine and possibly ten satellites, the most remote of which revolves around it in a direction opposite to the others. The thing that distinguishes

Fig. 129. Saturn

Three photographs showing the peculiar ring about the planet. Photograph by the Yerkes Observatory

Saturn from all the other planets is the enormous ring system which surrounds it (fig. 129). The rings have the appearance of being a solid mass; they are in reality swarms of particles of unknown size (but probably small), which circle around the planet in the plane of its equator and, because of their great numbers, appear solid, just as a cloud floating around a mountain peak appears from a distance to be as solid as the mountain itself. The distance across the outside ring is about 11,000 miles. There is a gap of about 2000 miles between it and the next ring, which is approximately 18,000 miles across. This second ring is as bright as the planet itself. Inside it and joining it is a very faint ring about

11,000 miles across. The inner edge of this ring is about 6000 miles from the surface of the planet. Although these rings are of vast extent in the plane of the equator they are very thin, and when they are seen edgewise to us they are barely visible even in the largest telescopes. It is certain that they are not more than 100 miles thick, and probably not more than 50.

262. The discovery of Uranus. Only six planets were known until the year 1781, when William Herschel, a German musician who had migrated to England, discovered the planet Uranus. Herschel secured a book on astronomy and became greatly interested in the science. He immediately resolved to procure a telescope and explore the heavens for himself. In those days (about 1760) telescopes could not be purchased as at present, and it was necessary for Herschel to learn to make them. He first studied mathematics in order to understand the theory of making the curved surfaces for his mirrors. In spite of this difficult study, which was necessary before he could begin to construct a telescope, he mastered the task. He then began to grind mirrors, making one after another, each better than its predecessor. With a telescope of his own make, on an evening in 1781, Herschel detected an object in the sky which was invisible to the unaided eye and which appeared slightly different from a star. After following it a few nights he found that it was moving with respect to the stars, which proved that it was a member of the solar system. At first he thought it was a comet, but in a few weeks it was determined that it was a previously unknown planet. This aroused the greatest interest, not only among scientific men but among people in general. Herschel was recognized by King George III and made director of the Royal Observatory of England.

The planet Uranus has a diameter of a little more than 30,000 miles. Four moons have been discovered revolving around it in planes which are almost at right angles to the

plane of the planet's orbit. Like Jupiter and Saturn it is of low density, is in an early stage of its development, and cannot possibly be the abode of life.

263. The discovery of Neptune. The discovery of Neptune was one of the most striking things in the history of science, and proves the high accuracy of astronomical methods.

After a planet has been observed a few weeks, its orbit can be computed and the position it will occupy at any future time can be determined. Its motion depends not only upon the attraction of the sun but, to some slight extent, upon the attraction of other planets for it.

After Uranus had been discovered, its orbit was computed and the place it would occupy at future dates was predicted. In 1820, or about forty years after its discovery, it was found to be deviating very slightly from its predicted position. Between 1830 and 1840 the deviation had become still greater. The cause was a question of the greatest interest to astronomers.

The problem of finding the position of a more remote planet which might have disturbed Uranus from its position by the observed amount in these forty or sixty years was one of such great difficulty that the foremost mathematicians of the world did not even attempt to solve it. It was, however, boldly attacked by two young men who had just graduated from college — Mr. J. C. Adams, of Cambridge, England, and Mr. Joseph Leverrier, of Paris. Each worked independently of the other and, in fact, without announcing that he was attempting to solve the problem. Adams completed his work first, and found that if there were in a certain part of the sky another planet farther out from the sun than Uranus, it would have produced the deviations in the motions of Uranus which had been observed. He attempted, without success, to have it sought for both at Cambridge and at the Royal Observatory in Greenwich. In the meantime Leverrier, who had finished his computations by a method entirely

different from that used by Adams, arrived at essentially the same conclusion. He wrote to a young German astronomer, Galle, and asked him to search for the suspected unknown planet. Galle impatiently waited for night for the stars to come out, and within half an hour after darkness came he began his search and found the unknown body in almost the exact position assigned to it by both Leverrier and Adams.

Neptune is nearly 3,000,000,000 miles from the earth and can be seen only with telescopic aid. Its distance is so great that more than four hours are required for its light to come to us, though light travels at the rate of 186,000 miles per second or about 10,000,000 miles per minute. Yet it is bound to the remainder of the system by the invisible bonds of gravitation.

264. Comets. The planets are fixed in dimensions and shape and revolve around the sun in relatively simple orbits. There are other bodies, the comets, which differ in all these respects. They are not often visible and usually for but a short time. They often change their dimensions enormously, and move in most peculiar ways. Until two centuries ago they were regarded by people with superstitious terror and were supposed to foretell disaster.

The typical comet (fig. 130) is composed of a head whose diameter may range from a few thousand miles to a million miles. Inside of the head there is generally a brighter, star-like nucleus, and streaming out from it in the direction opposite from the sun there is usually a tail whose length may be as much as a hundred million miles.

About four hundred comets have been observed since the invention of the telescope, most of them too faint to be seen without optical aid. Their orbits lie in all sorts of directions, and they are usually very elongated. In fact most of them are so exceedingly elongated that at their remotest points from the sun they are many times the distance of Neptune, and it may be that some of them actually recede to the distance of the stars.

When a comet approaches the sun its tail streams behind like the smoke from a locomotive, but when it again recedes from the sun the tail goes out ahead like the rays from the headlight on a misty night. There is much speculation as to the causes of the phenomena observed in comets. It is supposed that there is some sort of an electrical repulsion,

Fig. 130. Halley's comet

Note that the tail of the comet extends and slowly disappears at a great distance across the sky. The light spots are photographs of stars, which appear elongated due to changes of position while the picture was being taken. Photograph by the Yerkes Observatory

and probably also pressure of the light radiated by the sun, which drives off the minute particles of which the tails of the comets are composed and makes them stream out ahead in the direction opposite to the sun.

265. Visible comets. While most comets are visible only through a telescope, some occasionally appear in great splendor. One of these, known as Halley's comet, returns after periods of about seventy-five years. Its orbit was first computed by Halley, who showed that the comet which appeared in 1682 ought to return again about 1757. He

thus predicted its return and described the circumstances of its appearance. Most people laughed at this; but as the time drew near, scientific men who knew the soundness of the principles on which the prediction was based became immensely interested in the question of the return of the comet. Halley's prediction was verified, for not only did the comet return, but twice since it has passed near the sun and become visible from the earth — the last time in 1910. Its next appearance will be in 1986. When it was near the earth, its head appeared to be nearly as large as the moon and its tail stretched one third the distance across the sky. In spite of these great dimensions it was not very conspicuous. Other comets have been seen which were so bright that they were visible even in the daytime.

The superstitions regarding the evil influences of comets have been dissipated by the advance of science, but many people still fear that if a comet should actually strike the earth, all life on the earth might be destroyed. The result, of course, depends primarily upon the mass of comets, about which nothing is certainly known. If the earth should pass through the tail of a comet — as has happened a number of times in the last century — no harm would be done. Even if the earth should collide with the head of a comet, it is not probable that there would be serious injury to the earth or the people who live upon it.

CHAPTER XXI

THE SUN AND OTHER STARS

266. Questions for Discussion. **1.** The earth is so far from the sun (92,900,000 miles) that we cannot understand what the enormous distance really means. Can you devise a demonstration which will give a better sense of this distance? **2.** The diameter of the sun is 866,000 miles. How many earths side by side would be required to extend directly through the sun? **3.** Since the earth receives but a very small part of the light and heat which is radiated from the sun, what becomes of the rest of the radiated light and heat? **4.** What is a spectroscope? How does it enable astronomers to determine the nature of the sun and stars? **5.** Are some of the stars like our sun in the sense that they are centers of great solar systems? **6.** Are there stars which are larger and which give off more light than our sun? **7.** Why do we not receive more light and heat from the larger stars? **8.** By use of the text discussions and a star chart see if you can locate the following: the Big Dipper, the Pleiades, the North Star, Cassiopeia, Pegasus, Orion, the Milky Way.

267. Distance and size of the sun. When we are told that the average distance of the sun from the earth is 92,900,000 miles, we at once realize that we have no appreciation of the meaning of such a distance. It may help if we interpret in terms of some of the things we do or see others do. For example, if we could ride without stopping from the earth to the sun in an aëroplane which travels at the rate of 100 miles an hour, it would take one hundred and six years to reach the sun. This means that if a very speedy aëroplane could make a continuous trip from the earth to the sun, it would require for the trip something like the whole amount of time that has passed since your great-grandparents were little children. If an athlete who can run 100 yards in ten

seconds could run around the earth for one year without stopping, he would in that time circle the earth over seven times. If he could run at the same rate from the earth straight to the sun, it would require over five hundred years for him to make the trip one way; and we need not discuss his return trip, for long before his return human history would have undergone fundamental changes and our generation would be all but forgotten. It is said that the shortest time in which anyone has made the trip around the earth is thirty-seven days. At that rate it would take one year to reach the moon, four hundred years to reach the sun, and one hundred million years to reach the nearest star.

Possibly a better illustration is the time it would take for sound to travel from the sun to the earth. As a matter of fact, sound could not travel from sun to earth, since there is no atmosphere through which it travels — the earth's atmosphere probably extending only a little more than a hundred or at most a few hundred miles from the earth's surface. In our atmosphere sound travels at the rate of approximately one mile in five seconds. At this rate, with an intervening atmosphere like ours, we should hear the reports of the explosions which occur on the surface of the sun after an interval of about fifteen years. That is, an explosion which occurred on the sun's surface at the time when you entered the first grade of school would be heard by you at about the time you are graduated from college.

268. The earth's orbit and the size of the sun. The distance between the earth and the sun is not always the same, since both bodies move constantly in certain courses known as their orbits.

The circumference of the earth's orbit is about 600,000,000 miles. When this number is divided by the number of seconds in the year, it is found that the earth moves in its orbit at the rate of about 18.5 miles per second. The orbit is so immense that the curvature in a distance of 18.5 miles is

only about one eighth of an inch. This serves also to indicate how far we are from the sun.

When the distance of the earth from the sun was known, it was easy to find the sun's actual diameter. The measurements which have been made show that its diameter is 866,000 miles. This means that the volume of the sun is more than a million times that of the earth. In fact, if the earth were placed at its center, a tiny particle compared to the immense sun, and if the moon were revolving around it just as it does at present, the moon would be less than half the distance to the surface of the sun. It would take 330,000 bodies such as the earth on which we live to make one body as great in mass as our sun.

269. Source of the sun's heat. It follows from the enormous amount of light and heat energy received from the sun that the amount radiated by this great body must be beyond our imagination. The earth as seen from the sun would be a point in the sky and would intercept only $\frac{1}{2000000000}$ of the amount of light the sun radiates. It is found upon computation that every square yard of the sun's surface is giving off energy at the rate of about 70,000 horse power. Its temperature, therefore, is so high that we have no adequate means of understanding it, though we can approximate its measurement. The temperature of the sun has been computed and shown to be about 10,000° F. at the radiating surface; and the interior is certainly much hotter. This temperature is approximately twice as high as can be reached in the most powerful electrical furnaces so far constructed.

270. Storms on the sun. The sun's surface is disturbed by the most violent storms (fig. 131), as might be anticipated from its great mass and extremely high temperature. Some of these storms produce what are known as sun spots, which in appearance are black spots ranging from a few hundred miles to fifty thousand miles across.

The sun should be regarded as a largely gaseous mass, which is in a state of wildest tumoil and confusion, with terrific storms involving masses of matter hundreds or even thousands of times as large as the earth — some moving on its surface with a speed of hundreds of miles a minute, others shooting up from it with a speed exceeding a hundred miles a second and ascending to heights of hundreds of thousands of miles. This idea of the sun is very different from that of the ancients, who imagined that the sun is a piece of

FIG. 131. Explosions on the sun's surface

Photograph by the Yerkes Observatory

burnished metal drawn across the sky by a chariot and horses and that this little earth on which we live is the principal object in the universe.

271. Constitution of the sun. Although we are able to measure the distance, dimensions, and mass of the sun, until 1860 it was supposed that we should never be able to find out of what it is composed. The invention of an instrument called the spectroscope opened a new world to us. Its operation depends upon the fact that when matter is in a gaseous state the kind of light which it radiates depends upon the composition of the radiating gas. For example, gaseous hydrogen radiates certain kinds of light, gaseous oxygen other kinds, and gaseous iron, copper, etc. still other kinds. No two known substances in a gaseous state radiate exactly the same kind of light, just as no two strings on the harp give forth the same sound.

The spectroscope is an instrument which makes it possible to analyze the light received from any source. When the light of the sun has been analyzed, it is found that in its atmosphere there are certainly about half of the elements of which the earth is composed. Among them are such familiar things as hydrogen, carbon, oxygen, potassium, calcium, iron, nickel, copper, zinc, silver, tin, and lead. Most of the elements known on the earth which have not been found in the sun are the nonmetals, such as chlorine, iodine, sulphur, nitrogen, and phosphorus. Although they have not been found upon the sun, they probably exist there. Perhaps there are a few heavy metals, such as gold, mercury, and platinum, which have not been discovered in the sun. These heavy substances probably lie so deep in its interior that the light from them does not get beyond its surface. It is possible that as the storms on the sun bring more deeply placed materials to the surface, many elements not yet recognized may later be detected.

272. Nature and distance of the stars. It was once supposed that the sky is composed of a more or less solid substance in which the stars are embedded as jewels and that the whole structure revolves about the earth. We now know that the earth turns on its own axis and that it revolves in its orbit about the sun. We also know that the other bodies have motions more or less similar to those of the earth. The stars are so far away from us that their position relative to one another seems to us to change but little. The position of the planets relative to the stars changes constantly. By this fact the planets, although they look like stars and are often so called, can readily be distinguished from the stars; the stars form a relatively permanent pattern, but after a few days or weeks the planets can be seen to have changed position among them.

The stars are immense suns, most of those we see being much larger than our sun and millions of times larger than

our earth. In light-giving power some stars are 100 times, some 1000 times, and some even 10,000 times as great as our sun. Our sun would be invisible without telescopic aid if it were as remote from us as are most of the stars which we see.

The sun gives us more light and heat in a second of time than all the stars together do in fifty years. Since, in many cases, they are larger than our sun, they must be exceedingly remote. The nearest one which can be seen from the United States is 5,000,000 times as far away as we are from the sun. It is so far away that eight years are required for its light to come to us at the rate of 186,000 miles per second. Since most of the stars we see on a clear evening are many times this distance, we are made to feel almost helpless in our effort to understand the meaning of space. Some stars are so far away that light reaches us a thousand years after it is radiated, and the telescope shows stars which require many thousands of years for their light to reach us.

273. Stars of different magnitude. The 20 brightest stars are taken together and are called stars of the first magnitude. They are about two and one-half times as bright as the next group, which are called stars of the second magnitude. Examples of these are the Pole Star and the stars in the Big Dipper. In the whole sky there are 65 stars of the second magnitude. Stars of the second magnitude are two and one-half times brighter than those of the third, of which there are 190. Similarly, the third magnitude is two and one-half times brighter than the fourth, and so on. The faintest stars which can be seen with the unaided eye are of the sixth magnitude. There are in the first six magnitudes altogether about 5000 stars, only half of which are above the horizon at one time. Ordinarily one cannot see more than 2000 stars at one time on a clear evening. Under high magnification, however, innumerable stars may be seen, and sometimes these appear merely as great masses of nebulous matter (fig. 132).

274. The constellations. Any observer will note that the stars are grouped in such ways that the brighter stars often form more or less conspicuous figures. For example, the Big Dipper (fig. 133), and the Pleiades, as well as several other

FIG. 132. Spiral nebula
Photograph by the Yerkes Observatory

prominent groups, are recognized by most people. The more prominent groups of stars or constellations were given fantastic names by ancient peoples. The imagined forms of constellations furnished the basis of many primitive myths, and although the myth has passed away, the names are still used.

275. Stars visible in October, November, and December.[1] In the limits of so brief an outline as that here presented it is not possible to do more than suggest a few of the more important and easily recognizable constellations of our sky, and to show how further studies may be made by those who are interested. It is assumed that the time for the position named is the middle one of the three months

FIG. 133. The Big Dipper

Photograph taken so as to omit almost all stars except those which compose the dipper. Note that the second star from the left is a so-called double star. Photograph by the Yerkes Observatory

and about eight o'clock in the evening. For the first month the position would be about 15° east of the positions indicated, and for the third, about 15° west.

The North Star and the Big Dipper are easily located. The Big Dipper is composed of a group of bright stars so arranged that the handle and bowl of the dipper are visible in the northern sky. The stars of the dipper move in such

[1] There are several types of star charts or cards which may be secured from book dealers. Some of these are so constructed that they may be set for any day of any month during a period of years. Such charts or cards should be used in connection with this discussion in order that each pupil may make his own study of the stars. By use of such a chart this part of the text will serve as a guide for observations, but it should not be used as the basis for mere memory work.

a way that the whole dipper seems to revolve with the handle turning on the dipper point as an axis. The Big Dipper is a part of the larger constellation known as Ursa Major, or the Great Bear, referred to later. If a line is drawn through the two stars of the part of the bowl opposite the handle, and this line is extended above the bowl a distance about six times the distance between the two stars, this line will lead to a star of similar size and clearness, the North Star, or Pole Star. The two stars are known as the "pointers." For unknown ages the Big Dipper and the Pole Star have been used as guides by travelers in the night.

If in the month of November, about eight o'clock at night, the observer faces the north, he will find above the Pole Star, about three fourths of the distance from the north horizon to a point directly overhead, a zigzag of seven stars of the second and third magnitudes which constitutes the constellation Cassiopeia, known as "the woman in the chair." To most people it does not look like a chair, but like the letter W. The bright star which forms the bottom of the right-hand half of the W is a "double star," as is also the one near the middle of the third stroke of the W. The double nature of these stars cannot be determined except by use of a telescope, but it is interesting to know that in the second case the two suns revolve around their common center in a period of about two hundred years. At the time when Cassiopeia is visible, as indicated above, the Big Dipper is directly under the pole and so near the horizon that it cannot be observed unless the sky is very clear.

If the observer faces the south, and looks a little to the west of the south point and up about two thirds of the way between the horizon and the zenith, he will see the constellation Pegasus, which can be recognized from the fact that in it there are four stars which form a large square known as the "Great Square of Pegasus." There are no other conspicuous stars in this region of the sky.

West of Pegasus, almost straight west from the observer, and nearly halfway up from the western horizon to the zenith is a diamond-shaped group of stars in the constellation Delphinus. This group is often called "Job's Coffin."

276. Stars visible in January, February, and March. In February, at eight o'clock in the evening, directly to the east of the Pole Star is the Big Dipper. To the west of the pole is Cassiopeia. If the observer faces the south he will see a brilliant star just east of his meridian and about one third of the way up from the horizon to the zenith. This is the great first-magnitude star Sirius, in the constellation Canis Major, or the Great Dog. Although this star is comparatively near to us, only three or four being nearer, it requires 8.4 years for its light to come to us, and its distance is 50,000,000,000,000 miles. It is approaching us at the rate of about four miles per second; but this change, which will amount to more than 100,000,000 miles in a year, is of little relative consequence and will make no noticeable difference in its brightness for thousands of years. If Sirius should suddenly cease to exist we should continue to see its light for over eight years afterwards.

A little farther to the east, and somewhat higher than Sirius, is another first-magnitude star, Procyon, in Canis Minor, the Lesser Dog. Almost straight north of Procyon, and about straight east from the observer, are two stars of about the same magnitude, in the constellation Gemini, the Twins. The reason they are called the "twins" is obvious when one looks at them. The more northerly of the two is called Castor, the other one is Pollux. About ten degrees southwest of Pollux is an open cluster of stars called Præsepe, the Beehive, which can easily be seen on a clear and moonless night.

Immediately west of the meridian, and about halfway from the horizon to the zenith, is the group of stars known as Orion (fig. 134), located in the most brilliant part of the

sky. In the legends of the ancients Orion was a giant and a mighty hunter who in the sky stands facing Taurus, the Bull, which is somewhat to the west of him. In Orion there are three stars in a straight line running from the upper right to the lower left. They constitute the belt of the warrior. Just below them is a line of three fainter stars, which at this time of the year runs nearly up and down. On a clear night the central one of these three will be seen to be a little fuzzy. In fact, it is not only a star, and a so-called triple star, but also a tremendous mass of glowing gas called a "nebula." Its diameter is several million times the distance from the earth to the sun and is equal to the distance from the earth to Sirius. The bright white star which is a little below, and somewhat to the right of the belt of Orion, is Rigel, a first-magnitude star, which in light-giving power is at least 10,000 times as great as our own sun.

FIG. 134. Orion

In making this photograph the camera was arranged so as to omit most of the stars of the region, thus showing the imaginary warrior, Orion, more clearly. Photograph by the Yerkes Observatory

To the right of the belt of Orion and somewhat above it, or at a point almost straight southwest and about halfway between the horizon and the zenith, is the great constellation Taurus. Near its center is the red star Aldebaran, which the ancients represented as the eye of the bull.

North and northwest of Aldebaran is the small group of seven strikingly arranged stars called the Pleiades. Six of the seven are of the fourth magnitude and are easily visible without optical aid. The seventh, which is at one end of the group and near the sixth one, is not readily seen.

No group of stars in all the sky has attracted so much popular attention as the seven little stars of the Pleiades nor has been involved so frequently in the classical writings of the ancients or in the stories of primitive peoples. They are the "seven sisters" of the Greeks, the "many little ones" of the ancient Babylonians, the "hen and chickens" of the peoples of many parts of Europe, the "little eyes" of the savage tribes of the South Pacific Islands, and the "seven brothers" of some of the tribes of the North-American Indians. In November (on or about the 17th) they cross the meridian at midnight, and many primitive peoples began their year at that time. It is said that on that exact date no petition was ever presented in vain to the kings of ancient Persia. The Pleiades had an important relation to the religious ceremonies of the Aztecs of Mexico, and certain of the Australian tribes held dances in their honor.

Almost straight overhead is the constellation Auriga, the Charioteer, which contains the white first-magnitude star Capella. Capella is really a twin star, the two stars visible only in a spectroscope. Capella means "she-goat," and near it are three fainter stars which are called "the kids." This star is receding from us at the rate of twenty miles per second and will, on this account, eventually become dimmer. It radiates about two hundred times as much light as is given out by the sun.

277. Stars visible in April, May, and June. In May, at 8 P.M., the Big Dipper is almost exactly above the Pole Star. The Great Bear extends north, south, and west of this group, but all except the dipper is faintly shown.

The stars of the Big Dipper constitute a great group having nearly parallel motions. In the Big Dipper the star at the head of the handle is called Mizar. It is about 7,000,000 times as far from us as the distance from the earth to the sun, and seventy-five years are required for its light to come to us. Its faintness is due to its great distance, for it radiates 115 times as much light as the sun.

In the south, a little to the west of the meridian, is the constellation Leo, the Lion. It is marked by the sickle, the end of whose handle is the bright star Regulus, which will be seen about two thirds of the distance between the horizon and the zenith. The blade of the sickle extends to the north of Regulus and opens to the west. Near the third star in the Sickle is a very faint one, which is a severe test for keenness of sight. One of the interesting things in connection with Leo is that it is in this part of the sky that numerous meteors are seen about November 14, each year. Three times in a century this display becomes unusually magnificent.

Almost straight east, and about three fourths of the distance from the eastern horizon to the zenith, is the fine orange-colored star Arcturus, in the constellation Boötes, the Hunter. This star is so far away that a hundred years are required for its light to reach the earth. This means that in light-giving power it is at least five hundred times as great as our own sun.

278. Stars visible in July, August, and September. In August, at 8 P.M., a small but very interesting group of stars known as Lyra, the Lyre or Harp, is almost directly overhead. It contains a very brilliant bluish-white first-magnitude star called Vega.

The sun, with all its planets, is moving in the direction of Vega at the rate of about 400,000,000 miles a year, but the distance of this star is so enormous that no appreciable change in its brightness will be produced by this motion in the

FIG. 135. A gaseous nebula called "North America"

This peculiarly shaped nebulous mass lies in the Milky Way. Photograph by the Yerkes Observatory

next ten thousand years. The exact distance of Vega from the earth is not known, but it is thought to be more than 3,000,000 times as far as the distance from the earth to the sun. An interesting fact about Vega is that in twelve thousand years it will be our Pole Star. This does not mean that

Vega will move over to the position that the Pole Star now occupies, but that the axis of the earth will change until it points in the direction of Vega. This change is produced by the attraction of the sun and moon for the equatorial bulge of the earth. Nor will Vega be permanently the Pole Star, for the position of the earth's axis changes continually, completing a circle in the heavens in about twenty-six thousand years.

Just west of Lyra is the large constellation Hercules, the Kneeling Hero. It contains no bright stars. In the south, and a little to the west of the meridian, is one of the faintest groups of stars in the whole sky. This is Scorpio, the Scorpion. It can always be recognized by its fiery-red, first-magnitude star Antares, which in light-giving power is several hundred times greater than the sun. Antares is represented in mythology as occupying the position of the heart of the great scorpion. According to a Greek legend Scorpio is the monster that killed Orion and frightened the horses of the sun so that Phaëthon was thrown from his chariot when he attempted to drive them.

279. The Milky Way, or Galaxy. Everyone has observed the great band of stars which extends across the entire sky and is known as the Milky Way (fig. 135) because its stars are so thick as to give the appearance of an immense stream of milk. The hundreds of millions of stars are grouped more or less definitely into aggregations or constellations. There are probably at least 500,000,000 of them, and all together they are known as the Galaxy. The sun at the present time is somewhere in the interior of the Galaxy.

PART V — THE EARTH'S CRUST

CHAPTER XXII

HOW ROCK BECOMES SOIL

279. Questions for Discussion. **1.** Sometimes in the coldest winter weather, when a bottle of milk has been left out of doors, it is found that the cover is lifted and the milk stands above the top of the bottle. What lifted the cover? Why? **2.** In mountainous regions in winter, even in quiet weather, pieces from the faces of bare rocks are broken off and fall, though nobody has in any way disturbed the rock. What probably causes this to occur? **3.** What will take place if a strong metal cylinder filled with water and plugged tightly is placed where the water will freeze? **4.** Sometimes the bricks in the most exposed wall of a building crumble much more rapidly than those on less exposed sides. How can you account for this? **5.** Why is it that a sharpened stake which in the autumn was driven into the ground is lifted out during winter weather? **6.** Explain how winter or early spring weather lifts clover or alfalfa from the ground. **7.** What is a glacier? How do glaciers affect the soil of glaciated regions? **8.** Is the soil of your region of glacial or of sedimentary origin? **9.** How do plants and animals contribute toward breaking rocks into smaller pieces?

280. The surface of the earth. About three fourths of the solid surface of the earth is covered by water. The water has different depths in different places. The floors of oceans and lakes, like the uncovered land surfaces, are undulating in nature. Sometimes whole mountain ranges and the intervening valleys are covered by the same body of ocean water.

Conspicuous irregularities in the uncovered land surfaces are easily noted in mountain regions, and even in the most level plains some irregularities in the surface appear. The nature of this unevenness — abrupt or gentle slopes, long or

short slopes, long ridges or round knolls, etc. — gives distinctive character to a landscape and does much to determine the type of agriculture in a region.

In places the surface is readily seen to consist of solid rock (fig. 136), and solid rock may be found anywhere if the surface material is penetrated. It is thought that ages ago, when the earth's surface was newly exposed, the surfaces were all solid rock. A study of the development of conditions which we now see presents most interesting questions.

FIG. 136. The solid rock

Solid rock may always be found at a relatively short distance from the surface. Here the layer of soil is particularly thin. (Presque Isle, Michigan)

In some parts we find good soil and abundant natural vegetation; in others, rich garden soil which makes our commercial gardens possible; in others, undrained swamp lands; and in still others, sand and bare rock. How have these regions come to be as they are?

281. The surface and water. If the earth's surface were perfectly level, water which falls upon it would not flow off in any definite direction. With the unevenness that exists, water runs from higher to lower levels except where absorbed and held by the surface materials. Thus, in the development of the earth's surface, water has accumulated, making pools in some places, lakes in others, and oceans in others. Where

water runs over the surface of the earth, it follows the depressions until it finally comes to a place of so low a level that it no longer flows. When the difference in level is great enough between two places which are near one another, water runs rapidly from one to the other. If the difference is abrupt, a waterfall is formed. Falling water wears away the hardest rock if the falling continues long enough. Not only does the water itself wear the rock upon which it falls

FIG. 137. Freezing water breaks the rock

Note that last year's plants grew in crevices of the rock

but many large and small pieces of rock are carried by it, and these add greatly to its cutting power.

282. The work of freezing water. Water may readily enter crevices in the rock. When it freezes it expands, and its expansive force is very great. Alternate freezing and thawing may break the rock into smaller and smaller pieces. An interesting experiment to show the effect of freezing water may be made by filling a strong metal cylinder with water, plugging the ends of the cylinder tightly, then placing it where the water will freeze and carefully noting the results.

Along rocky cliffs where water runs into crevices and freezes, one may often observe its effects in breaking up the rock (fig. 137). Tons of rock may be pushed aside a short distance by the expansive force exerted through the freezing of a small amount of water. When we think of all the small crevices in rock into which water may run and afterwards freeze, we may imagine the enormous amount of work that is done in breaking up rock.

283. Disintegration of rock by water. Rock often contains substances, such as lime, salt, or compounds of sulphur, which may be taken up in solution in water. If water has filtered for a long time through rock which contains soluble substances, the rock is made porous by the removal of these substances. Great caves, as the Mammoth Cave, Kentucky, have been made in this way. If the water is heated (as sometimes occurs within the earth's crust) or if it contains acids, its dissolving effects are much greater.

Streams and waves of water are also important factors in disorganizing rock. In streams stones are rolled, turned, and ground over one another and constantly worn thereby. In swift-flowing mountain streams very large rocks are torn from their positions, rolled over and over, and often carried down to levels where the current is not so swift. From the large rocks smaller pieces are broken and are then carried downstream to places where the current is much less swift than where the larger rocks are left. From the mouth of a stream to its mountain source, soil and rock particles show the carrying power and wearing power of the stream. Many of the finer rock particles may be carried by the stream until it reaches the large body of water into which the stream empties — sometimes the ocean. When streams overflow their channels, there is an abundant deposit of fine soil particles that were carried by the water.

Along the shores of lakes and in the riffles of streams there may constantly be seen the process of wearing rocks

into smaller and smaller particles. This same action of the water also sorts the materials into the different sizes, and one may find these sizes assorted in definite regions as he passes from the shore into deep water.

FIG. 138. A valley glacier

A glacier on the slopes of Mount Rainier, Washington. At the lower end the ice is covered by the broken stone which it is carrying. Photograph by Dr. G. E. Nichols

284. Glaciers and the earth's crust. In former times glaciers were important agencies in changing the earth's crust, and in some places their work is still going on (fig. 138). The glaciers have been formed by tremendous accumulations of ice, which fell as snow and then, by pressure of its own weight, became ice. Ice, like water, flows toward places of lower level, though it flows very slowly. As it moves it may

grind or tear away the rocks in its path and carry the fragments along with it. Often these rocks are ground over one another, and marks or scars are left as evidence of their contact and the force which acted upon them. When the temperature becomes warmer or when the glacier reaches a

FIG. 139. The end of a glacier

The ice is covered with stones and gravel. In the foreground is an accumulation of the material which has been brought down by the glacier. Photograph by Dr. G. E. Nichols

place of warmer temperature, the ice may melt, thus leaving the rock and sand that were carried (fig. 139). The melting ice forms streams which, as they flow from the glacier, carry away some of the solid material.

A large part of North America (fig. 140) was once covered by glaciers, and we still have many evidences of the tremendous effect they have had upon the surface and upon soil formation. Much of the richest soil of the central United States

was brought to its present position by glaciers. A study of the maps of Illinois, Iowa, and other states will show that the soil of the so-called corn belt is of glacial origin.

FIG. 140. The continental glacier

The map shows the extent of the continental glacier in North America. After the United States Geological Survey

285. Effect of plants and animals. When the roots of plants grow into crevices of rock, they often exert sufficient force to split it (fig. 141). Many lowly plants, such as

lichens and mosses, grow upon the surfaces of rock, and the organic products (acids) formed by them assist in disintegrating the rock. When once a little broken rock and organic soil material has been formed, other plants and animals may then grow and may in their turn make further contributions to soil-making. Unless this soil is washed away, it may constantly increase in its depth and productivity.

FIG. 141. Action of plants upon rocks

The roots of plants enter crevices and break the rock. Here there is not enough soil to cover the rock, and the pine trees are rooted in the sandstone

286. The soil and its significance. It is customary to speak of the soil as including the top layer of earth material. The term is sometimes used to apply to whatever earth materials there are upon the solid rock. In agriculture and gardening the term applies to the more nutrient layer in which plants grow.

The soil is the natural growing place of most plants and many animals. The roots of plants are usually embedded in

the soil. In the case of many plants the stem is also underground, as is true of the dandelion, plantain, parsnip, and radish. Plant roots spread more or less in the soil, sometimes many feet from the rest of the plant, and may also descend to considerable depths. From the soil these roots secure various substances. The soil serves not only as a source of supply of food materials but also gives anchorage to the plants whose roots are embedded in it. Many animals also live in the soil, and all of them are dependent directly or indirectly upon the plants that grow within or upon the soil. Animals such as the earthworm, the gopher, the fox, and the hedgehog burrow in the soil, and thereby secure food in the form of plant roots or decaying organic matter, or secure homes that furnish them a measure of protection from enemies or from extremes of temperature.

CHAPTER XXIII

PHYSICAL STRUCTURE AND FERTILITY OF THE SOIL

287. Questions for Discussion. **1.** What kinds of soils in your community are considered the most valuable? For what purposes? Is most of the soil in your community of this best type? **2.** What are the different kinds of soil recognized in your state? To what extent does the value of farm lands vary according to the predominant kind of soil? **3.** Are the drained lowlands more fertile than the highlands? Why? **4.** In what ways do plants and animals contribute to the development of soils in uncultivated areas? Can you prove that plants help to form soils? **5.** How do earthworms contribute to enrichment of soils? **6.** Do you know any reason for cultivating the soil other than killing weeds? **7.** What effect would a heavy growth of weeds have on the underground water supply available for crops? **8.** In loose, sandy soils, near rivers or lakes, to what level is it necessary to dig to secure a supply of water? Does this have anything to do with cultivation of the soil? **9.** Which is heavier, a cubic foot of dry sand or a cubic foot of dry clay? **10.** What causes a desert? Are all deserts sandy?

288. Kinds of soil. If we examine a handful of the soil from near a lake shore we may find it chiefly composed of sand. Sometimes this sand is coarse or gritty and sometimes it is almost as fine and smooth as flour. Near the water's edge quite coarse sand may usually be found. Back from the lake, where plants are growing abundantly, the sand is discolored and contains the substances resulting from decay of plant and animal bodies. Where decayed organic matter is abundant the soil is called loam. In some streams of water along the riffles small stones are found in large numbers, and more or less sand is mixed with them. This material is gravel, and a soil in which such material predominates is gravelly soil. Often by digging only a little way down we find a soil which is composed of very fine and compact

material — so compact that when moist it may be pressed into balls which will hold together when thrown with great force. This is known as clay. "Silt" is the name applied to the fine, rich soil that is deposited by currents of water. It is commonly deposited on broad bottom lands at times of high water. In low, swampy ground plants may grow in great quantity and fall down year after year. Their bodies partially or completely decay and become pressed into a porous soil known as peat. It must be obvious that these different kinds of soils may be found mixed together in various ways; indeed, any one of them is usually found with one or more of the others.

289. Structure of the soil. If pure, coarse sand is examined under magnification, it is readily seen to consist of many small rock particles. Some are flattish, some are cubical or oblong, some have sharp corners, and some are well rounded. The surfaces of these small particles of rock are glistening and glasslike. In fact, glass is made by melting pure sand together with other substances. An examination of sand of different degrees of coarseness readily shows that the difference is due to variation in the size of the rock particles of which the sand consists. In sand that is fine enough to be blown by the winds the particles are usually so small as to look like dust, but upon magnification their rocklike nature appears.

Clay consists chiefly of extremely small particles which fit together so as to make a compact soil — so compact that, when quite dry, pieces of this soil are sometimes said to be "as hard as rock." A high power of magnification is required in order to distinguish the smallest rock particles in clay soils. Mixed with the finest clay particles we sometimes find sand, peat, or gravel, the result being sandy, peaty, or gravelly clay.

We may therefore have many gradations in soil: from finest clay to coarse clay; from finest sand to coarse sand, and on to coarse gravel and even to rocky soil; from sandy

or clayey soil with but a slight amount of decayed organic matter to peat in which there is little or no clay or sand. In nature these soils are found in all possible mixtures. A careful study of the table in section 290 will enable you to learn a good deal about how soils may be mixed and also about the size and percentages of the different parts of which they may be composed.

290. Size of soil particles. Careful measurements have been made of the actual size of the particles of different kinds of soils, also of the percentage of air space in these soils. The following table presents the data for a few types:

Kind of Soil	Diameter of Particles	Percentage of Pore Space
	mm.	
Fine gravel	2–1	37.60
Coarse sand	1–0.5	39.88
Medium sand	0.5–0.25	34.43
Fine sand	0.25–0.10	35.32
Silt	0.05–0.005	44.15
Clay	0.005–0	52.94

291. Plants and animals as soil-formers. In sand upon which plants have grown for a year or more, magnification will usually show, in addition to the sand, some of the remains of plant roots, stems, or leaves, although these may have decayed to an extent that makes it difficult to recognize their origin.

When peat is examined under magnification little or no sand is seen, but this soil consists of the more or less disorganized particles resulting from dead plant and animal bodies. Peat is so nearly pure plant material that when dry it makes a fuel of importance in some parts of the world; it is cut from the earth in brick form, dried, and then sold in the markets. Sometimes peaty soils get afire and may burn slowly for weeks or even months.

While rock particles are the basis of most soils, these particles alone would furnish little support for animal and plant life. As already shown, dead plant bodies may accumulate so as to produce almost pure plant material in the form of peat. In deep woods we have another illustration of the deposition of plant material in large quantities. Leaves, twigs, and stems of plants fall and decay, thus forming a layer rich in humus, in which luxuriant growths of plants are found. To be fertile all soils must have some humus in them; one of the great problems of modern agriculture is to supply by natural or artificial means the organic matter that may decay and produce the needed humus.

The influence of earthworms in soil formation is often very large. They eat their way through the soil, thus making burrows. In their bodies digestive fluids are added to the soil that has been eaten, and when this is voided from their bodies the soil is changed so that its fertility is increased. The burrows of the earthworm provide added opportunity for air to enter the soil — a matter of much importance. A garden with many earthworms in it is likely to be a rich garden.

292. Raw materials for plant food. There are numerous elements that plants need in order to grow well. The most important of these are carbon, oxygen, hydrogen, nitrogen, iron, phosphorus, and potassium. The carbon is obtained from the air; for from a three-thousandth to a ten-thousandth of ordinary air is carbon dioxide, a compound of carbon and oxygen. All the other elements are secured from the soil, where they appear in various combinations. Obviously a soil is fertile that has an abundance of the needed substances and that does not hold other injurious substances, for instance, plant poisons, which sometimes do exist in the soil. Very little is known about plant poisons in the soil, but recent investigations show that some plants excrete substances which may be injurious to them and possibly to other plants. Much attention is now being given to problems of soil fertility.

Water is one of the most important substances of the soil. Plants use water directly as a raw material for food manufacture, and they also use other materials which are secured from the soil only when they are dissolved in water. If water were absent from the soil, plants would starve; and if there is too much water, some plants will drown from lack of air.

293. Loss of nitrogen from soil. Where the soil is covered with a growth of wild plants, and nature is allowed to take its way unmolested, it is not probable that in the long run there is any decrease in the amount of nitrogen compounds in the soil. The nitrogen compounds are absorbed from the soil by the roots of plants, but they remain in the plants, and when these die and decay, the compounds, at least the greater part of them, are returned to the soil. On cultivated ground the case is quite different. There the whole plant or a part of it is harvested and taken away, and the nitrogen which the removed part contains in the form of protein and other compounds usually does not return to the soil. In a grain of wheat there is 12.2 per cent of protein, of which a large part is nitrogen. It is calculated that in reaping a crop of 20 bushels of wheat from an acre, the farmer is removing 25 pounds of nitrogen; at that rate there would be a deficiency of nitrogen compounds in a few years unless the loss could be replaced in some way.

We have spoken of the loss of nitrogen only; it may be that other necessary minerals are exhausted in a similar manner, but this matter is not well understood.

294. The supply of nitrogen. It is a common practice to return to the soil, in the form of manures, as much as possible of the straw and other materials which have come from the fields, and in this way much may be done to maintain the fertility of the soil. There is always a loss, however, in the material that is sold and taken off the farm, and there are certain other unavoidable losses of nitrogen compounds. A very important source of nitrogen is found in the action

of certain kinds of bacteria which live in the soil or in the roots of the clover and other plants of the pea family. As stated in section 316 their value lies in the fact that they cause the nitrogen of the air to combine with other elements in such a way as to form the soluble nitrogen compounds which other plants can absorb and use. It is common to restore the nitrogen supply of land by planting it to crops of clover, alfalfa, cowpeas, or other related plants.

If the use of these plants and their bacteria does not restore the land, it is possible to scatter over it certain nitrogen-containing chemicals. The substance which was used most commonly before the world war, and which is still somewhat used, is a nitrate called Chile saltpeter, which is mined in great quantities in Chile and exported by shiploads. Nitrogen and other important plant foods are now secured in large quantities from tankage, dried blood, etc., produced by the meat-packing houses, and from ammonium sulphate, which is produced in the coke ovens. Important processes have been discovered by means of which the nitrogen of the air can be secured and used for agricultural and other uses. Large factories are being constructed for the purpose of preparing commercial supplies of nitrogen compounds by use of nitrogen from the air.

295. Value of the soil. It is not alone the farmer who is interested in the soil, for upon its fertility depends the production of foodstuffs for all of us. If it is generally lacking in the substances and conditions necessary for plant growth, there will not be enough food produced to supply the needs of the country, and all will suffer either in the prices paid or because of lack of food.

CHAPTER XXIV

SOIL WATER, DRAINAGE, AND IRRIGATION

296. Questions for Discussion. **1.** What kinds of soils are most likely to remain sticky for some time following a rain? Can you determine why this is true? **2.** If a piece of clay, a similar piece of black loam, and a pile of pure sand are placed upon a heavy wet blotter, will all the soils become moist and with equal rapidity? Will they become equally moist? **3.** Is a wet soil colder or warmer than a dry soil? Why? **4.** How much water is used in making a ton of ordinary clover hay? How much would be used in making the hay of a twenty-acre field at the average rate of acre yield in your locality? **5.** To save the water supply in time of drought, is it best not to cultivate the soil? Why? **6.** Why should artificial drainage be used in most soils? **7.** To what extent is artificial drainage used in your locality? Is there a noticeable difference in yield in artificially drained regions as compared with those not drained? **8.** Where are the chief irrigation projects of the United States? **9.** If there were enough water available, do you think the solution of the world's food problems might be helped materially by irrigating the arid lands of the United States? **10.** Does dry farming promise large returns in production? Why? **11.** Where are the chief swamp lands of your state? What is being done toward reclaiming them? **12.** What advantages would there be to the United States from the possession of a kind of wheat which would not be injured by drought?

297. Amount of water in the soil. It is commonly observed that coarse, gravelly soils do not hold water for a long time and that fine soils do. If a series of glass tubes are filled with soils of different degrees of coarseness, and the same amount of water is poured into each, it will be noted that less flows out from the finer soil. Why is this? Water may be held in the soil in either of two ways: it may adhere closely to the surfaces of the soil particles, in which case it is known as water of adhesion, or it may be free between

soil particles (fig. 142), when it is known as free water. Most of the free water may flow away if there is adequate outlet for it, but adhesion water is not easily removed.

Obviously the more surface exposed, the more water may be held by adhesion. In the finer soils much more surface is exposed than in coarse soils. This may be illustrated readily by measuring the exposed surface of a cube, then cutting the cube into many small cubes, measuring their surfaces, and comparing the last measurement with the first. A marble exactly 1 inch in diameter will just slip inside a cube 1 inch on each side and will hold on its surface a film of water 3.1416 square inches in area. If, however, we reduce the diameter of the sphere to one thousandth of an inch, it will require 1,000,000,000 of them to fill the cubic inch completely, and their aggregate surface area would be 3141.59 square inches. In coarse silt the surface area of the particles reaches an astonishing figure, since in 1 cubic foot of such soil the particles would have a surface area of 37,700 square feet. So large a surface area makes possible a large water content. In some kinds of clay 100 pounds of the wet soil may contain 40 pounds of water, or 40 per cent of the whole weight. Since 1 cubic foot of clay ordinarily weighs about 80 pounds, 40 per cent of it, or 32 pounds, might be water. These facts make clear the tremendous differences in the water-holding power of soils.

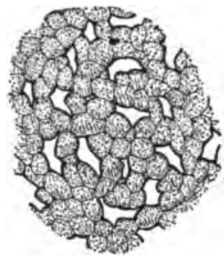


FIG. 142. Distribution of soil moisture

Diagram to represent soil particles, each covered by a film of water. In wet weather or immediately after a rain all the spaces might be filled with water

298. Soil water and soil temperature. Anyone who has walked back and forth along the lake or ocean shore while in bathing has noticed differences in the temperature of the soil, and any well-trained gardener who desires to grow early spring vegetables selects what he calls a "warm soil." What

do these things signify? Soil which is very wet changes temperature much more slowly than dry soil (sect. 158). The water of the soil, being at a lower temperature than the air near the ground on a sunny spring day, makes the soil feel cold. If in the hot summer weather the soil may be cultivated in such a manner that the water will be held in it, the soil will not become so hot and will therefore be a better living place for plants.

299. Amount of water used by crops. From the calculations given it is evident that some soils may contain much water, but it is true that large amounts of water pass off from the soil by evaporation and that plants take large quantities of water from the soil. Growing plants are constantly carrying water through their roots, stems, and leaves, using some of it in food manufacture but allowing most of it to pass off into the air. The following data show the average quantity of water used by three common farm crops:

Corn: 50 bushels per acre require 1,500,000 pounds of water.
Potatoes: 200 bushels per acre réquire 1,268,000 pounds of water.
Oats: 29 bushels per acre require 1,192,000 pounds of water.

It has been estimated that in producing a ton of clover hay, which after drying is 85 per cent dry matter, 375 tons of water are carried into the air during the growing season, either through the plant or by evaporation directly from the soil. There may often be a yield of more than 2 tons of clover hay to the acre, but assuming it to be 2 tons, the amount of water taken from the soil to make the crop is equal to more than 6 inches of rainfall. It is estimated that water equal to a rainfall of almost 10 inches is used in producing a crop of corn of 50 bushels per acre. What amount of rainfall is there in your locality during the growing season?

300. Soil water as affected by tillage. The ways in which farm and garden soils are cultivated have much to do with their water-holding capacity. When water evaporates from

the surface of compact soils, the water from below, if there is any, immediately comes to the surface. Water passes readily through relatively solid soils.

If an extremely fine-drawn glass tube is placed with one end in a dish of water, the water will rise some distance in the tube. This action is known as capillarity. The fine spaces between the walls of the soil particles act as capillary tubes, and the soil water passes upward if the soil is compact enough to have the spaces continuous.

The action of the soil may be illustrated by using a piece of compressed sugar. Touch one end of the lump to a liquid, and the liquid soon goes through the entire lump. In the same way in dry weather compact soils lose their deep soil water through evaporation. Another experiment, with two lumps of sugar, will suggest a method of cultivating soils so as to hold moisture. Allow a second lump to lie loosely upon the first, which just touches the liquid, and the liquid will pass into the second very slowly if at all. The so-called capillary connections within the lumps of sugar are not continuous between the two; there are no continuous lines along which the water passes. In the same way constant surface cultivation of the soil keeps the capillary spaces broken, and water does not pass upward through the soil rapidly. If the soil is deeply plowed at the beginning of the season and thoroughly cultivated on the surface throughout the season, there is (1) a reservoir for catching water and (2) a device for preventing its rapid evaporation.

301. Natural drainage of soil water. Water may be drained from soil by surface drainage or by underground drainage, and either may take place naturally or artificially. When rains or snows leave more water on the soil than it will absorb, the water flows away toward regions of lower levels. When very heavy rains fall in a short time or when snow that lies upon frozen or rocky soil thaws rapidly, the run-off may be very great. When rain falls slowly, the soil will take

up quantities so large that if it had fallen in a brief time floods would have been produced. Surface drainage naturally results in making streams of water, which flow together, finally forming a large stream, which may by means of its tributaries drain many hundreds of thousands of square miles. A river system is a natural system of soil drainage.

Under the surface the water also flows toward a lower level, and these subterranean currents may sometimes open to the surface as springs or natural wells, or open directly into watercourses and thereafter augment the surface streams. The level at which water stands beneath the surface — the

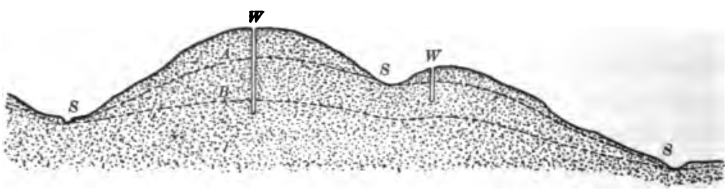


FIG. 143. The water table

Diagram to represent the water table in a series of hills and valleys. Line *A* represents the position of the water table in wet weather; line *B*, in dry weather; *S*, springs; *W*, wells

water table, as it is called (fig. 143) — varies in its depth below the surface in different regions. The deep clay and rock layers of the earth are often undulating, and the water table conforms to these undulations. For example, in digging a well for a domestic supply of water one farmer reached the water table and secured an abundant supply at a depth of 16 feet. Another farmer, less than half a mile away, had to dig 48 feet before he secured water. Underground water may exist in layers of rock or clay. Artesian wells are usually made by boring into deep layers of water, so as to strike the water in the lower parts of the layer. The pressure from the higher portions of the same layer will cause the water to rise to the surface, and sometimes it is sufficient to cause the water to rise many feet into the air.

302. Artificial drainage of soil water. Much of the surplus water of the soil will naturally drain downward to the water table, but agricultural plants grow better when by artificial drainage as much water is removed as will readily flow into underground drains. The advantages are probably at least fourfold: surplus water is removed, the soil is better aërated, the soil becomes warm earlier in the season, and injurious soil substances excreted from plant roots may be removed as the surplus water passes downward. If you will plant two jars of seedlings, one in a well-drained glass jar and the other in a jar without drainage, and give them the same amount of water, you will see some of the advantages of soil drainage.

303. Irrigation. In many parts of the country the annual rainfall is so small, or is confined to so short a period of the year, that there is not sufficient water in the soil to enable plants to grow. There are many hundred thousand acres of soil the composition of which is favorable to the growth of plants but which are deficient in water. Various devices are used for irrigating some of these lands, with different degrees of success. There are in the United States (fig. 144) over 10,000,000 acres of artificially watered lands, and projects under construction will add much to this figure. There are several methods of irrigation, but that along the banks of the Rio Grande River may serve as a type. In the lower stretches of this river the annual rainfall is quite low, but a large volume of water comes from the mountainous country hundreds of miles away in Mexico and the United States. In the lower Rio Grande Valley there is much rich alluvial soil, needing only water to make it fertile. Hundreds of miles of ditches have been constructed to direct the water from the river to the land. A main canal, looking like a river, carries water in one case for more than 100 miles. From this main canal smaller ones branch off, and finally the smallest ditches run to the individual farms. Floodgates are used in turning water

upon the fields when it is needed. In this way, with an abundant supply of water and with constant sunshine, a rapid and luxuriant growth of plants is made possible.

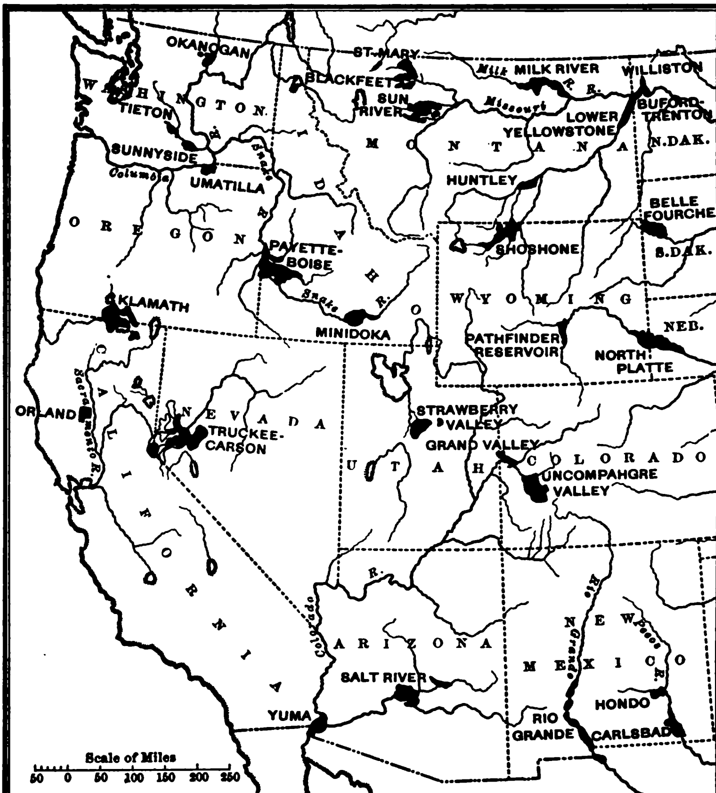


Fig. 144. Irrigation in the United States

The map shows the location of the more important government irrigation projects. There are in addition many other areas irrigated by government, private, and state enterprise. From map by the United States Reclamation Service

It must not be forgotten that underground drainage is advantageous for other purposes than the removal of surplus water, though at times even irrigated farms need it for

that purpose also. The failure to introduce underground drainage in irrigated districts is now beginning to prove a limiting factor in the production of plants, and doubtless such drainage will soon become usual there.

304. Source of water for irrigation. The larger part of our irrigation projects consists in diverting mountain streams into

FIG. 145. An irrigation dam

The Roosevelt dam on Salt River in Arizona is 280 feet high and 1080 feet long. The water which it holds back forms an artificial lake with an area of 25.5 square miles. The impounded waters are expected to irrigate 190,000 acres of land. Photograph by the United States Reclamation Service

near-by valleys. Sometimes streams are dammed (fig. 145) either to assist in diverting the water or to store it for later use. Tunnels have been made through mountains, and elevated aqueducts have been built over valleys to carry these streams. In some regions irrigation by use of deep wells is practiced. Water is pumped into reservoirs, and from these

it is led off through ditches to the fields. In case of rivers which flow through flat valleys the water is sometimes pumped into irrigation ditches or into elevated reservoirs.

305. Dry farming. In some parts of the United States there is an amount of rainfall which would give the soil sufficient water to produce a crop if evaporation could be prevented. In some such regions the experiment has been tried of keeping the soil under surface cultivation for a long time. First, deep plowing is done, furnishing a deep soil for the absorption of rainfall. Then constant surface cultivation retains most of the moisture, and after a time enough moisture may thus be caught and held to make it possible to grow a crop. In some cases where this type of farming is done the rains are so scanty that a crop can be grown only once in two years. Possibly some water may be drawn upward from the deep soil, but most of it must come from the scanty and infrequent rains.

It is evident that dry farming requires much labor in order to put the soil in proper condition for the production of a crop. Even with these difficulties fine crops have been grown by dry farming, and when we consider the extreme cheapness of land in the dry-farming regions, the relative amount of labor seems well repaid in results. Dry farming is still somewhat in the experimental stage, and whether it is to be extended to cover other large areas where there is scanty rainfall cannot be safely predicted. In any event, there are large areas of dry land which receive no rain, or practically none, and these areas must look to some form of irrigation to make them productive. The quantity and availability of the water supply have thus far limited irrigation to relatively small areas, though the total acreage seems large. Whether the Great American Desert is to be obliterated and become a highly fertile region is largely a question of the quantity and availability of water. There may be sources of water supply (from deep wells or from the air) not yet within the range of

practicability, but these are for future developments. There is untold wealth in the soil of the arid regions for those who can put a good supply of water upon it.

306. Reclamation of swamp lands. The opposite of arid soils is found in such extensive areas as the undrained or poorly drained everglade swamps of Florida, the Dismal Swamp of Virginia and North Carolina, the swamps about our inland lakes (both large and small), and the overflowed areas along the lower stretches of our great rivers. The United States Geological Survey estimates that in this country there are over 100,000,000 acres of undrained swamp land, much of which is drainable. Along the Atlantic coast alone there are estimated to be over 3,000,000 acres of drainable soil. Often this kind of soil is the most productive when it is properly drained.

In the United States large drainage systems have been built that are in a way comparable to the irrigation systems. One removes the water, the other adds it. In the Everglades of Florida thousands of acres of fertile soil have been made tillable by the construction of large drainage ditches.

As people are coming to understand better the fundamental importance of the soil in the life of all the nations, they are making constant effort to render greater areas of arid and swamp soils available for use in agriculture, horticulture, and gardening, and as homes.

CHAPTER XXV

EROSION AND SEDIMENTATION

307. Questions for Discussion. **1.** Brush is sometimes thrown into a gully to check washing. How does it accomplish this? **2.** Why are hillside farms sometimes terraced? **3.** It is sometimes reported that floods have increased in the Mississippi Valley as the country has become settled and forests have been cleared away. How might removal of forests affect floods? **4.** How do you account for the fact that the soil, at least at the surface, is usually more moist in forests than in adjacent fields? **5.** Why is the soil of lowlands, such as bottom land along rivers, usually more fertile than upland soil? **6.** Does the continual but slight loss of soil from a field represent a money loss? Why? **7.** Why is it desirable to maintain trees on steep slopes? **8.** May the deforestation of steep hillsides do injury to owners of other property? How? **9.** What are the chief regions in your country which illustrate loss of soil by erosion? **10.** What is being done to prevent this loss? **11.** What efforts are being made in your state to develop a permanent forestry policy? Is this being done partly with reference to the state's soil or water needs, or for a supply of timber?

308. Removal of the soil — erosion. When the formation of soils was being discussed we spoke of the action of water upon rocks, gravel, and sand. We have but to look at a large river (fig. 146) or a gutter stream to get an idea of the power of water to carry soils. A study of a surface stream that is flowing from a field or garden will tell a good many things about erosion. First, the heaviest particles of soil that are moved are carried only by the strongest part of the current. This part of the current may also carry all finer grades of soil material, but the slowest part of the current may be so very slow as to carry only the finest particles. If a dam is made across a very small stream the heaviest materials are dropped where the current is first slackened, and some very

fine material may not be dropped for a long time. If a tumbler of muddy water is allowed to stand, an estimate may be made of the time required for all the silt to settle to the bottom of the tumbler. This will show how long the water, if moving, might have carried silt.

If one digs up two squares of soil of similar size — one bare and the other of turf — and both are then subjected to a

Fig. 146. Erosion by a stream, Tumwater Cañon, Washington

A swiftly flowing stream wears down its bed rapidly and forms a steep-walled valley. Photograph by W. B. MacCallum

stream of water from a hose, it will be seen that the turf withstands the running water much longer than does the bare soil. Erosion takes place less rapidly when soil is covered or when it is held by plant roots.

In wooded regions, where there is much undergrowth and humus, the water from rain flows from the surface very slowly. In an open field the same rain will produce quite a stream. The stream upon the field is soon gone, and the surface

becomes relatively dry. In the woods no stream appears for quite a time, and then it is small, but it lasts for a much longer time than that in the open field; when it stops flowing, the soil of the woods is still very moist (fig. 147). The trees and undergrowth retard the falling rain. Humus acts as a sponge in holding large quantities of water, so that streams start slowly; and when they do start, the leaves, twigs, and bushes retard the movement so that the ability of the water to remove soil and to carry it is held in check. Humus retains much of the moisture after the stream has stopped flowing. Furthermore, the covering of trees tends to reduce the loss of water by evaporation.

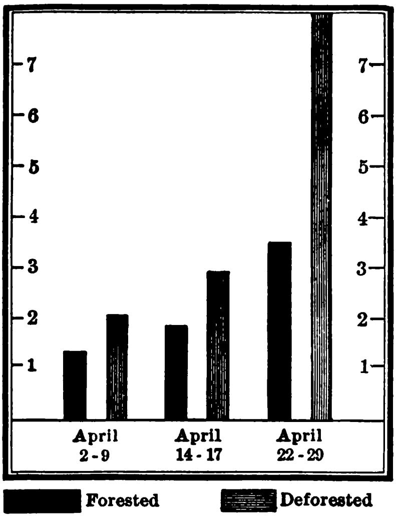


FIG. 147. Effects of forests upon drainage

Diagram to represent run-off from two similar areas in White Mountains, one of which has been deforested. The vertical bars represent in inches the proportionate run-off. Note that the forested area retains the larger amount of water. From data by the United States Geological Survey

309. Loss from water erosion. The damage done to soils by erosion is very great. The soil is carried away, the fields are cut into deep gullies, and often the owner of the land realizes too late that the best part of his soil has passed entirely beyond his control (fig. 148). Obviously regions with hilly topography are more subject to erosion than level fields. Such fields will lose less soil if they are kept planted in grass, as pasture or meadow, or in timber. In some places, where hilly land must be cultivated, it is terraced around the hills in order to prevent erosion or to catch any soil that may be moved by water.

The great importance of erosion of soils is suggested by the fact that the Mississippi River is estimated to carry over 1,000,000 tons of sediment into the Gulf of Mexico every day, or over 400,000,000 tons per year. Professor Salisbury says: "It would take nearly 900 trains of 50 cars each, each car carrying 25 tons, to carry an equal amount of sand and

FIG. 148. A late stage in erosion of deforested area

The gullies have broadened until the whole of the original surface has been removed excepting where vegetation has protected it. Photograph by the United States Forest Service

mud to the Gulf. All the rivers of the earth are perhaps carrying to the sea forty times as much as the Mississippi."

310. Vegetation and erosion. When visiting the banks of a stream which has recently overflowed we usually find silt or mud deposited upon the plants along the banks. The more dense the vegetation, the larger the quantity of silt deposited. In many overflowed regions deep layers of rich soil have been built up through periodic deposits made in this way (fig. 149). Where the water of the stream is flowing rapidly, it can carry

its load of silt, but when its rate of flow is reduced, it drops part of its load.

Not only does vegetation exert a strong influence upon the deposit of silt but it also helps to prevent erosion. The parts of plants above the soil retard the flow of water, and the roots within the soil help to prevent the removal of

Fig. 149. Deposit of soil by rivers

The shaded portion in prehistoric times was a part of the Gulf of Mexico, but has been made into rich lands chiefly by deposit of material carried down by the rivers. Redrawn from *Popular Science Monthly*, 1916

soil. In many places one may see instances in which water has been turned aside and the soil left where plant roots were well established. One of the most effective ways of preventing erosion along hillsides and stream banks is by introducing rapidly growing plants which help to hold the soil.

311. Deposit of soil from erosion. It is estimated that at least one third of the sediment carried by streams of water reaches the sea. The other two thirds is deposited in various ways. A study of a stream bank will almost always show

the formation of deposits of gravel, sand, and silt. In times of overflow of the channel banks this deposit is large, but we must remember that erosion is also large at such times. When streams overflow, the velocity of the water is usually decreased and much of the load of soil is dropped. In this way large areas along the Mississippi River are annually replenished by the richest soil (fig. 149). Great dangers attend such overflow, however, and effort is made to prevent it by building strong dikes in the attempt to hold the river within the channel.

At the mouth of such great rivers as the Mississippi and the Yangtse the accumulation of sediment has built up great deltas. Much of the tremendous quantity of soil thus carried into the sea goes far from shore and doubtless sooner or later settles to the bottom to contribute its part to filling the ocean basins. Since this sediment has been eroded from the highland areas, it is evident that its removal from one place and deposition in another contributes slowly but surely to the processes of leveling the earth's surface.

In China part of the people near the mouth of the Yangtse River flood their fields at a time when the river is heavily laden with silt, in order to replenish their soil. After the silt is deposited, the water is drained away. Untold wealth in soil is constantly being lost to the human race through erosion, and the problem of maintaining the fertility of the soil is annually made more difficult thereby.

312. Erosion by wind. We have but to recall the dust clouds of windy days to see clearly that the air has a soil-carrying power, and if we will keep a moistened surface, as that of a glass or a towel, in the dust-laden air for a few minutes, we shall be able to get some notion of the quantity of this dust. Snow soon becomes colored by dust carried by the wind from places where the soil is exposed. The air is never entirely free from dust. This air-borne dust is deposited everywhere and in some places has accumulated in immense banks known as loess.

Sand is carried by air currents, and, as in the case of water, the strongest currents carry the largest pieces. Along the shores of lakes and oceans the action of wind-blown sand is readily seen (fig. 150). Sometimes it cuts the bark from trees and carves out the softer portions of large rocks. The finest sand may be carried great distances.

FIG. 150. Erosion by wind

The hill to the right, a sand dune, is being blown away in spite of the protecting cover of vegetation. At the left, sand is burying a group of trees

In some regions the winds build dunes, or hills, of sand, those of coarsest sand near the shore and those of finest sand farthest away. Some of these dunes may keep moving inland as sand from the windward side is carried over and dropped on the leeward side. A dune may thus migrate far inland, and with a change of prevailing winds it might migrate back to the shore or even into the lake or ocean. Sometimes vegetation gains a foothold on a dune, and plants may live upon it for ages; then winds may again bring sand to the dune, cover the vegetation beyond the tops of the

tallest trees, and later uncover all and even remove the dune upon which they stood.

In some of our Western states, as Kansas and Nebraska, there are wide stretches of sandy soil which in some places forms dunes. On some of the cultivated land great annoyance is caused by the soil blowing when it is fresh-plowed; at times the soil drifts along fence rows much as snow drifts in winter. *American Forestry* says:

> When the soil is broken, the soil blows so badly that hundreds of "nesters" who have tried to make a start in this region have moved out only when their fields have blown into the next section or county. On a bright day in spring in the sandhill section of Kansas, with what is known in that country as only a brisk wind, it is possible to locate all the plowed land for from fifteen to twenty miles around by the dense clouds of sand that stånd out against the blue heavens like pillars of gray smoke.

CHAPTER XXVI

LIFE IN THE SOIL

313. Questions for Discussion. **1.** With your school ground or some other known plot of ground as a basis for study, prepare a list of all the living things you know which live on or within this piece of ground. Then from your text or other source add to this list all the microscopic forms which you think might live there. Is it true that the soil teems with living things? **2.** What is the relation of aphides to the growth of a crop of corn? of ants to aphides? of the bird known as the flicker to the ants? Is the destruction of the flicker helpful or harmful to agriculture? **3.** How do bacteria affect the supply of nitrogen in soils? **4.** Why is it that nitrogen-producing bacteria are not present in some old soils? **5.** Why are bacteria necessary to the best growth of clover, alfalfa, and cowpeas? **6.** From your state agricultural experiment station get a bulletin which tells you the best ways to plant clover, alfalfa, and cowpeas so as to insure the presence of the proper bacteria. Make a class report upon this topic. **7.** What is the chief bacteria-using crop in your country? How long has this crop been extensively grown? Are most farmers successful with it? How could they be more successful?

314. Living things in the soil. We have already mentioned some of the living things in the soil, but there are others, chiefly microscopic, which need further discussion. There are many small animals — for example, the earthworms already discussed — the larvæ of many kinds of insects, many adult insects, and many microscopic animals of the lower forms of life. In addition to the roots of living plants there are many kinds of lower microscopic plants, chief of which are the bacteria. These animals and plants live upon organic and mineral matter in the soil, and not only through their life processes but by the decay of their dead bodies they contribute to the organic matter available for higher plants.

315. Interrelationship of living things in the soil. The different things living in the soil may prey upon one another quite as do things that live aboveground. The soil is often filled with a dense population of living things, some living upon mineral matter in the soil, some upon dead organic matter, some upon other living things.

An instructive illustration of the extent to which these interrelations may go is seen in the case of the roots of the corn plant and certain animals that may often be found upon or near these roots. Extremely small insects, known as plant lice, or aphides, bite into the tender roots of the corn and suck out the nourishing juices. The aphides are almost stationary animals and cannot ordinarily make their way from one plant to another without assistance. When well nourished they excrete small drops of a glistening, sweetish solution sometimes called honeydew. This honeydew is an article of food for certain black ants which also live in the corn fields. It has been found that the ants will dig furrows down at the side of the corn plants until they can reach the roots, and will then carry the aphides and place them upon younger and more tender roots. When food for the aphides becomes scanty they are moved to new plants. The aphides thus secure abundant food, and the ants secure the honeydew as their own food. Both are parasites upon corn, one directly, the other indirectly. Corn and grass are often killed by these animals, and the soil, rendered porous by the burrows, dries more rapidly than it otherwise would. This is but one of many illustrations of the interrelationship of animals and plants in the soil.

316. Bacteria of the soil. In connection with the discussion of bacteria those living in the soil were mentioned, but there are additional statements to be made.

Bacteria are present in most soils in very large numbers. They are of very many kinds, and they affect the soil in a number of ways. Some of them live upon dead bodies or

parts of bodies of plants and animals, and in so doing they change these things so as to increase the organic content of soils. Bacteria and small animal forms are highly important as instruments of decay in the soil. Different kinds of bacteria carry on different stages in decay. One group of them breaks up ammonia, forming nitrogen compounds that higher plants can use. It will be remembered from an earlier statement that nitrogen is one of the things essential to plant growth.

But there is another group of soil bacteria of peculiarly striking interest. These are often found growing in great numbers in little nodules (or tubercles, as they are called) on the roots of clover, beans, peas, and other plants that are related to these. It has also been found that these tubercle bacteria are able to use nitrogen from the air of the soil and combine it with oxygen in such a way that higher plants, as corn, wheat, and oats, can then use it. One of the greatest problems in maintaining desirable fertility of soils consists in keeping the proper supply of nitrogen compounds. Plants other than these bacteria cannot use the free nitrogen of the air at all, but the tubercle bacteria can do so and thus make it available to higher plants. Plants such as clover, peas, etc. do not grow so well when bacteria are not present on their roots, and the compounds of nitrogen that are needed for subsequent crops are not deposited in the soil.

317. Soils and man. Since we are all dependent upon the things that grow from the soil, we are all interested in the origin and structure of soils and in the maintenance of their fertility. In this country our ancestors had a rich, unused soil when agriculture began. It was so rich that they thought it quite inexhaustible. But already, in the parts of the United States that have been longest cultivated, soil has become so unproductive that in some cases it is worth but little. The waste of one generation can be replaced only by the increased care and intelligence of succeeding generations.

PART VI. LIFE UPON THE EARTH

CHAPTER XXVII

THE PLANT COVERING OF THE EARTH

318. Questions for Discussion. **1.** See if you can learn what the chief features of the native-plant covering of your region were before men began to cultivate it. How much of this native plant life now remains? Was it right to remove it? **2.** If you have swamp lands, dry, hilly regions, and regions of medium conditions in your community, state what characteristic differences there are in these three types of regions. What makes the differences in plant life? **3.** Can you prove that plants and erosion are gradually filling the lakes and swamps and may eventually make them into tillable fields? **4.** Make a list of the uses of plants which you encounter in one day. **5.** What wild plants growing in your neighborhood are of value? **6.** Secure, if possible, the value or amount of the principal crops of your community. **7.** What industries in your town depend mainly upon plants for their existence? Which do not depend upon plants at all? **8.** Would it be wise to allow the original native-plant growth to remain in good agricultural land? **9.** Are there any areas in your community which might have been more valuable if left covered by native vegetation? Why? **10.** Why are plants killed when salt brine is poured upon their roots? **11.** Explain what occurs when dried raisins or prunes placed in a dish of water soon become plump in form.

319. Abundance of plants. In the preceding chapters there has been frequent reference to living things, and some of them, such as bacteria, have been studied. Almost everywhere the surface of the land is covered with plants, if they have not been removed by man; and even where this has been done, man has usually introduced other plants to take the place of those he has removed. In countries with abundant rainfall they hide the earth so completely that the landscape is almost wholly green. Even in the desert there

are few large areas without sufficient plants to give tone to the landscape (fig. 151). The "bare" rocks of either dry or moist countries are usually partly covered with the plants called lichens, and there are plants on the mountains close to perpetual snow. Plants are found in great abundance in the waters of the ocean. The only land areas of considerable

Fig. 151. A desert landscape, Southern Arizona

The plants are not sufficiently numerous to entirely cover the soil. Photograph by Dr. D. T. MacDougal

extent which appear to be almost wholly devoid of plants are the interior of Greenland and the region about the south pole, and these are covered with ice. Even here the surface of the snow may be colored by a small red plant belonging to the algæ and commonly known as "red snow."

320. Variety among plant formations. The plant covering of the earth varies greatly in different regions. Each kind of plant needs for its growth certain conditions that may be

partly or entirely different from the conditions demanded by other plants. For this reason any place in which the soil, moisture, temperature, and other conditions are favorable to one or a few kinds of plants is likely to be an unfavorable place for certain other plants. Thus the hilltop, which affords just the right conditions for the growth of oak and

FIG. 152. Plant associations on the margin of a pond

Note the rushes in the water, the low-shrub and tall-shrub associations beyond, and the tree association in the background

hickory trees, is not equally favorable to the growth of elm or willow, and these are not usually found there. Plants which can find suitable conditions for their growth at the same place are likely to be found growing together. A group of plants which are commonly associated in this way is known as a plant association (fig. 152). There are many kinds of plant associations, and these constitute an important subject of study. Those types of plant associations in which trees form the most conspicuous part are known as

forests. There are other types in which the grasses are most important; these are known as grasslands or meadows.

321. Value of wild plants. Forests are usually regarded as the most valuable natural plant associations. They supply us with wood, which we use for many purposes. If it were

FIG. 153. Careful lumbering

The young trees have been protected while the older trees were cut, and the brush is piled for burning. After a few years another crop may be harvested. Photograph by the United States Forest Service

not for our forests we should be deprived of the use of wood, and it is difficult to see how we should secure adequate substitutes for some uses to which wood is put. It is of the greatest importance to our nation that the wood of our forests should be used in such a way as to prevent waste and destruction (figs. 153 and 154). The forest is also of much importance in preventing the erosion of the soil, as we have seen (sect. 308). If the forests are removed in mountainous

country the usual result is that the slopes are soon stripped of soil and neither forests nor anything else will grow. It is not probable that rainfall is increased by the presence of trees, but the water that does fall is better conserved in the forest than in the open country, and the streams which flow from the forested mountains are much more constant and

FIG. 154. Wasteful lumbering

The more valuable trees were cut, and the brush was allowed to lie upon the ground. Fire has destroyed not only the refuse but also the remaining trees and the young growth. There will be no second cutting for many years. Photograph by the United States Forest Service

uniform than those that flow from a region whose slopes are bare and rocky. For this reason forests are particularly important when they are located upon the sources of streams which supply water for irrigation in the lower valleys.

The grasslands in their natural condition are useful mainly for grazing (fig. 155). In the past a large part of the meat supply of this country came from the cattle raised on the great ranches which formerly occupied the Western prairies and plains. A large part of these grasslands is so level and

easily tilled that it has been transformed into farms wherever there is sufficient rainfall or a supply of water for irrigation. The land is more valuable for farming than it is for grazing.

Though both the forests and the grasslands are valuable, land that is suitable for agriculture will be of greater value when it is farmed properly than when it grows only trees and wild grasses. The best lands should be cleared of their forests, but there are many thousand square miles of country

Fig. 155. Grazing country

In some regions stock raising is almost the only industry. The land may be more valuable for this purpose than for any other, especially where it is hilly or stony. Photograph by the United States Department of Agriculture

in the United States which are so hilly or rocky that they cannot be farmed, and these areas ought to be preserved as forests in order that we may have a supply of timber and that rainfall may run off more slowly. There are also great areas of arid lands in the West which can scarcely be used for anything but grazing except when irrigation is practicable.

In order to preserve these benefits for the people, to protect important natural features, and to supply places of recreation and pleasure the national government and the states have set aside certain areas as forest reserves, parks, and game preserves.

322. Cultivated plants. Where the natural plants have been removed, it has usually been done in order to substitute for them our cultivated plants, for these supply products which we need for food, clothing, and other uses. There is no industry in all the world so important as farming. Its products are of more value than those of any other industry, and all industries depend upon it for their prosperity. Where agriculture thrives it makes a need for transportation facilities; on the other hand, many fertile regions have had their production stimulated through the introduction of railways, since without railways farm products find only a local market. In similar ways the other industries of the entire country are related to agriculture.

323. Plants and soil. In the chapters on soils we had frequent occasion to refer to the close relation existing between plants and the water content of soils. If we were to cut off the stem of some vigorously growing plant close to the ground, we should find that the sap would appear from the cut end of the remaining stub. A maple tree or a grapevine will show this escape of sap, or "bleeding," particularly well if a branch is cut off early in the spring. Maple trees are often tapped for the sap, which is evaporated to secure the sugar which it contains, sometimes a single tree supplying from thirty to fifty gallons of sap in one season. The sap is mainly water. Since the water comes out of the plants, there must be some place from which the plants secure it.

It is not at all difficult to prepare an experiment which will show that water is lost by the soil when a plant is growing in it. If a pot with a growing plant is wrapped in a sheet of rubber so that no water can escape excepting from the plant, it will be found that the soil becomes drier and that weight is lost. A similar pot of soil without a plant in it and completely inclosed in rubber does not lose in weight. We should conclude that the plant must have been taking up water from the soil about as rapidly as it evaporated from the leaves.

324. How plants secure water. The first question is, How does the water get into the roots? In order to answer this we shall have to study the peculiar behavior of solutions. This may be shown by the use of a dense sugar solution and pure water. A funnel which has been filled with the sugar solution and over the large end of which a piece of parchment paper has been fastened is inverted in a dish of water (fig. 156). Since the parchment paper is permeable to water, it might be supposed that the liquid in the funnel and the water outside would come to rest at the same level. This does not occur excepting possibly for a very brief period. The sugar solution increases in volume, and the level of the liquid in the funnel rises until it overflows the top of the tube. If a longer tube were attached the liquid might rise in it to a height of many feet unless the pressure due to the height of the column caused the paper to break.

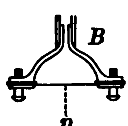


FIG. 156. A simple osmometer

A, osmometer, with the liquid in it standing at the height *h*; *B*, sectional view of osmometer, showing permeable partition *p*

Careful measurements of the water outside the funnel show that it decreases in volume just as much as the sugar solution increases. This means that water has gone through the paper into the sugar solution, although the pressure due to its height in the tube opposed the entrance of the water. At first but a little of the sugar finds its way out through the paper, as may be determined by tasting the outer solution. If there had been some sugar in the outer vessel of water, but a smaller proportion than within the funnel, we should still have had the same kind of result, but the more nearly the solutions on the two sides of the membrane are alike in amount of dissolved matter, the less will be the difference in pressure.

It is clear that the water passes through the partition and dilutes the denser solution, thus increasing its volume. Later the solutions have interchanged until they are very nearly if not quite alike. The membrane is said to be semi-permeable, because the water will pass through freely but the sugar will not pass so readily. The same results may be secured with other solutions and other membranes. This process by which water or other liquids may pass through a semi-permeable membrane between a weaker and a stronger solution, and by which the volume of the latter is increased, is called osmosis. The similarity of the results of this experiment with osmosis to the results of root absorption is striking.

FIG. 157. A root tip

The tip of a clover root covered with root hairs. Very much magnified

325. Root structure. When the tip of a root is examined, it is found to be composed of cells, as is any other part of a plant or animal. These cells resemble those seen in the leaf. They are thin-walled, and it is possible for water to pass in through the cell walls. The interior of the cell wall is lined with a layer of living substance (protoplasm) with a space in the center which contains cell sap. Cell sap consists of water and some substances (often including considerable sugar) in solution. This layer of protoplasm permits water to pass inward but it does not readily permit the sugar and most other substances which are dissolved in the cell sap to pass outward.

Each cell of the root is, in fact, an osmotic apparatus in which the protoplasm acts as a semi-permeable membrane, the cell sap being the more concentrated solution and the soil water the weaker one. If in our experiment we had used soil water and concentrated plant sap as the two liquids,

we should have been imitating the plant. Of course, if the soil water should be a more concentrated solution than the plant sap, water would be drawn out of the plant and it would die. This is what happens if a strong solution of salt is poured on the grass of the lawn.

The water which is taken in by the cells of the surface is passed from cell to cell farther into the root by osmosis and finally reaches the tubes or pores through which it is carried into the stem and leaves.

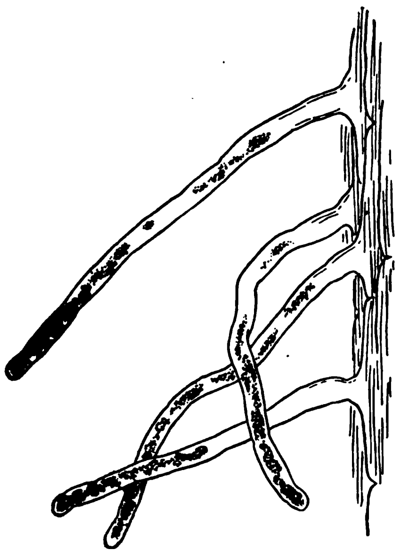


FIG. 158. Root hairs

These hairs add very much to the absorbing surface and assist in anchoring the root in the soil. Highly magnified

326. Root surface. Since water is absorbed only through the surface of roots, it follows that the rate at which it will be taken up will be affected by the amount of absorbing surface possessed by the roots. The amount of surface on each rootlet is very small, for only the part within a very few inches of the tip is permeable to water. The older and larger parts of the root are covered by a bark, or corklike layer, which is almost waterproof. Extensive branching of the roots and the presence of root hairs increase the surface of root exposure.

The root hairs are hairlike projections (fig. 157) which grow out from the surface of the youngest rootlets to a length of an eighth of an inch in some cases, clothing the end of the root in a "fuzz." They are not found at the tips of the roots, but the zone covered by them begins about a

quarter of an inch from the tip and extends back as much as an inch or more. Each hair is merely a tubelike extension of a cell upon the surface of the root (fig. 158), and it is able to absorb water just as the remainder of the cell does. A root hair usually has many times as much surface as the cell from which it grows, and the surface of the root is increased in this way. A single root hair is very small, but there are thousands of them on even a very short piece of root (1314 to $\frac{1}{100}$ square inch have been found on pea roots). They extend into the soil, from which they absorb water and in which they help to anchor the plant firmly.

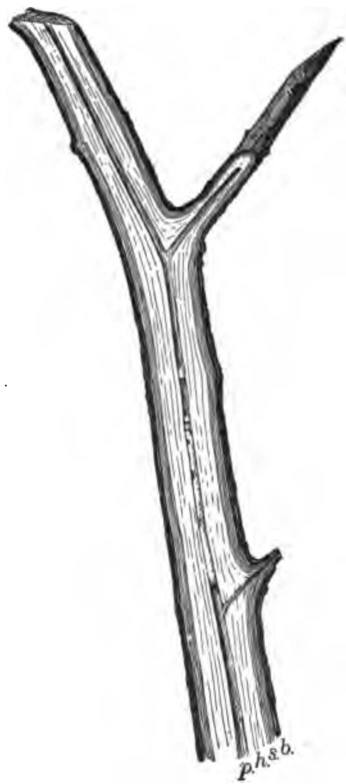


FIG. 159. Ascent of water

Longitudinal section of a stem showing route of ascent of water; *b*, bark; *s*, sapwood; *h*, heartwood; *p*, pith. Water ascends principally through the sapwood

The number of root tips in a single plant is ordinarily very great. We commonly judge the root system by what we see when a plant is pulled out of the ground, but usually much the larger part of the root system is broken off and left in the ground. The roots of a tree ordinarily spread much farther underground than its branches do aboveground. Not only do the roots spread widely, but by repeated branching they are divided into thousands of small rootlets, which penetrate so thoroughly to all parts of the soil that it is often difficult to find

under a tree a cubic centimeter of soil that does not contain rootlets. It is these small rootlets that bear the root hairs.

It must not be supposed that root hairs are roots. The hairs never become roots; on the contrary, as the root tip grows out farther the old root hairs die and new ones are formed on the newer parts of the rootlet.

FIG. 160. Transplanting a large tree

Note how the soil and roots are protected so that when the tree is planted, its roots will be able readily to gain anchorage and supply the rest of the tree with soil water. Photograph by *American Forestry*

327. Water-carrying tissues. We have already spoken of the way in which water passes from cell to cell in the tip of the rootlet and of the way in which it is transferred from the surface to the interior of the root. In some of the smaller plants, such as the mosses, water passes through the plant directly, but in all the larger plants there is a more intricate system by means of which it is carried. The structure of the water-carrying parts is so similar in roots and stems that we shall use a stem for our example. If we cut a stem with leaves from any of our common trees and stand it with the end in red ink for a while, we shall find that the ink has ascended the stem as

water would have done and has left a red stain which marks its path (fig. 159). This red stain is found only in that part of the wood which is near the bark. This means that the water moves up the stem or root in the wood which lies next the bark and which is known as the sapwood.

Closer examination of the wood will show that it contains numerous large pores, and it is through these that the water travels. These pores may easily be seen in oak wood. The cause of the rise of water in the stems of plants is not wholly understood.

328. Root surface and transplanting. It is ordinarily impossible to remove plants from one place in the soil to another without causing serious disturbances to the root system (fig. 160). Many of the root hairs and smaller roots are broken off, as is usually true of parts of the larger roots. This means that in the new location there will at first be less absorbing surface than the plant previously possessed. Usually some of the roots become dry through exposure to the air and are of no use to the plant, thus further reducing the absorbing surface.

In transplanting, the branches and leaves do not necessarily suffer the same sort of reduction as the roots do. Since water continues to evaporate from the leaves, and since the absorbing surface of the roots is reduced, it is necessary to reduce the evaporating surface of the leaves by pruning. In this way the remaining leaf surface should not make too great a tax upon the absorbing power of the roots before new roots and root hairs are developed.

CHAPTER XXVIII

HOW FOOD IS USED BY PLANTS

329. Questions for Discussion. **1.** In what sense is chlorophyll sometimes properly called the magician food-maker of the world? **2.** What is meant when we say a modern field of wheat, corn, or oats is man's device for exposing chlorophyll to the light so as to make it do what he wants it to do? Is there the same meaning in a field of cotton? **3.** How does the world's food supply depend partly upon the fertility of the soil? **4.** When chinch bugs, grasshoppers, or crickets strip the leaves from wheat or oats the desired grain is not produced, no matter how favorable the soil and weather. Why? **5.** Is it a public as well as an individual matter for a farmer to allow his farm to become poor in its production of crops? **6.** How are domestic animals dependent upon chlorophyll work in plants? **7.** From the standpoint of the soil fertility why is live-stock farming better than grain farming? **8.** Should sewage be turned into streams and thus washed away? Why? **9.** In what ways is plant food used to satisfy the needs of the plant itself? **10.** Is plant food made and stored in grains, etc. primarily for the good of men who use it? **11.** How are plant foods carried about through the plant? **12.** What is meant by saying that starch is a storage form of plant food, and sugar a transportation form? **13.** What plants produce most of our foods? **14.** Do plants as well as animals carry on processes of assimilation of food and processes of respiration?

330. Do plants need food? People often speak of the food stored in fruits, grains, stems, leaves, and roots as if those foods were made by plants for the purpose of feeding men. That is men's purpose in selecting and cultivating plants, and therefore they strive to cause plants to manufacture large quantities of the kinds of food which they desire. But plants are living things and, as such, must have foods by means of which to grow and to replace used or worn-out parts. Green plants have the power of making their own

food supply from the simple substances carbon dioxide and water and from the more complex compounds, which include nitrogen, phosphorus, and potassium.

If a plant is not interfered with, the food which it manufactures is commonly used by it and for its own purposes. For instance, a part of our food is composed of starch from wheat grains; but if the wheat had not been disturbed, the grains would have fallen to the ground, where, under favorable conditions, they would have started to grow into new wheat plants. These young plants would have used the food stored up in the grain. By harvesting, milling, baking, and eating the wheat we have appropriated for our own purposes that which otherwise might have fed a young wheat plant.

There are several purposes for which food is used in the plant. New material is needed for growth, since both the living protoplasm and the cell walls must be built up from food materials. A less obvious use of food is to furnish energy for the life processes of the plant. A part of the food manufactured by a plant undergoes chemical change by combination with oxygen, which is ordinarily secured through the leaves. This process is called respiration and serves the same purpose in the living plant that respiration does in the living animal. During part of its life the plant stores material in seeds or roots for the nourishment of the next generation of plants.

331. The kinds of foods. There are five classes of foods: carbohydrates, fats, proteins, mineral salts, and water. The first three are of chief importance.

The carbohydrates we already know from our study of the manufacture of plant foods in green plants. The process known as photosynthesis is the source of all the carbohydrates. The most common carbohydrates are starch and several kinds of sugar.

The fats, like the carbohydrates, contain carbon, hydrogen, and oxygen, but in different proportions. Cottonseed oil and

olive oil are familiar examples. There is some oil to be found in almost every plant.

Proteins are the materials of which the living substance is composed. They contain the same three simple substances as the carbohydrates (C, H, O), and also nitrogen, with (usually) sulphur, phosphorus, and other substances. They are the most complex chemical compounds and are not well understood. Proteins are most familiar to us in the form of the white of egg, cheese, and lean meat.

The mineral salts, such as common table salt, are inorganic chemical compounds. Many of them are of little importance as food materials, and they are never present in large quantities.

332. Where food is used. Since food is necessary in a growing plant as a supply of material from which new leaves, branches, and roots are constructed, it is evident that much of it will be needed in the more rapidly growing parts, and since food is needed by all cells for the process of respiration, food will be needed in all living parts. This means, of course, that there will be need of food to furnish energy everywhere excepting in a few dead tissues like the dry outer bark.

Although food is needed everywhere, it is not made everywhere. Carbohydrates are made principally in the leaves, but they may be needed in connection with the growth of roots or the development of the fruit or in other parts of the plant. This immediately raises the question of how food may pass from one part of the plant to the other, for very plainly there must be some method of transfer.

333. Method of transfer. Liquids, and solids dissolved in liquids, are able to pass readily from cell to cell, as we learned when studying the absorption of materials by the roots. It is, of course, perfectly easy to see how sugar may be transferred from one cell to another in this way, for the sugar which is in the plant is dissolved in the sap. By osmosis the sugar may travel from cell to cell in the leaf until it comes to

the veins, along which it travels to the stem and so throughout the plant. But what about other food materials? Most kinds of food material in a plant are not soluble. For instance, if we soak a potato or a quantity of rice in water, the valuable materials in it do not dissolve in the water, else we should find it of more advantage to drink the water than to eat the rice or potato. The fact is that in most foods comparatively little of the carbohydrates, fats, and proteins dissolve, no matter how long we soak the foods in water. In the examples mentioned the most abundant material is starch, and this is quite insoluble. Since food material is usually found in plants in the form of starch and other insoluble compounds, we must ask ourselves how it is that it can be transferred to the various parts of the plants where it is needed. Certainly the solid grains, such as the grains of starch, cannot travel far through the plant and remain unchanged.

334. Digestion of starch. In discussing how insoluble materials are moved through the plant, we shall take the specific example of starch and remember that the process for other insoluble foods is somewhat similar.

If we examine with a microscope some starch grains from a sprouting seed, where the food material is being carried away to be used in forming new parts, we find that the grains of starch are not smoothly rounded, as they would be at any other time, but rough, with many holes on the surface, as if some of the starch had been dissolved from each grain. Of course starch does not ordinarily dissolve in water, but it is rather easily changed into sugar (Chapter VII), and the sugar will dissolve. In plants there is a substance (called diastase) which has the peculiar property of causing starch slowly to change into sugar if the diastase is brought in contact with the starch. This substance is in the plant sap. It acts upon the starch at the surface of the grains, and the rough, pitted appearance shows where the starch has been so changed and dissolved.

It is not difficult to secure a solution containing diastase by crushing in water some sprouting seeds, as those of barley. If this solution is mixed with starch in a test tube, it will change starch into sugar as it does in the plant. The use of diastase to digest starch is a common trade process. Brewer's malt is simply slightly sprouted barley which has afterwards been killed by heat and drying. The diastase in it digests the starch, forming sugar, which may afterwards be fermented to form the alcohol which is present in beer.

The process such as we have just been describing, of changing an insoluble substance into a soluble one, is called digestion. It is possible to transfer insoluble foods from place to place through the plant only after they have been made soluble by digestion.

335. Digestion of other substances. Diastase will digest only the carbohydrates, but there are other substances which have a similar action on proteins and fats. Substances which, like diastase, cause chemical changes to take place in other substances while remaining unchanged themselves are called enzymes. There are a great many enzymes in plants, and digestion and many other changes are due to them.

336. Transference in the plant. As pointed out in the preceding paragraph, dissolved food materials may pass from cell to cell throughout the plant. When food reaches the large pores or tubes in the stem, it may pass upward with the general movement of water through the plant, as mentioned in the discussion of absorption and movement of water (sect. 327). Passage in a downward direction occurs through tubes in the inner bark. Immediately within the tissues through which the manufactured food passes downward is the layer of tubes through which water passes upward in the stem. The veins of the leaves are composed of tissues similar to those of living wood and bark, and liquid material moves in these as it does in the wood and bark. The veins are the supporting framework of the leaves.

337. Food storage. When the food is in solution and is therefore capable of being transferred from place to place within the plant, it may be disposed of in one of three ways: it may be used immediately for repair and growth, or it may be used in respiration, or it may be stored.

When food is stored it is usually changed into an insoluble form again. For example, sugar is commonly changed into starch, though there are cases in which sugar itself is stored. Food may be stored in almost any part of a plant, but usually it is stored in large quantities only in much-thickened parts. Examples of thickened storage parts are the potato, carrot, parsnip, radish, onion, beet, sweet potato, various bulbs and tubers, fleshy fruits, and seeds. Very often food is deposited in the roots and other underground parts of the plant. In these cases the food which is made and stored during the summer commonly serves for the plant's growth during the earlier part of the following season.

The large amount of food which is brought together within a small space makes these storage organs of plants an important article of food for men and animals. The starch and proteins stored in wheat are two of the valuable things in wheat, and this is the most important single food for the Caucasian race. In the Orient — China, Japan, India — the most important food storehouse is the rice grain, and a very large part of the human race is dependent upon it for their principal food. Rye flour is used for bread in some European countries. Beans and peas contain starch and more protein than almost any other common vegetable food. They are therefore particularly valuable as a substitute for meat in hot countries or in places where meat is scarce.

Corn and oats are used for human food, but not to so great an extent as some of the other grains. They are usually fed to animals, which may then be used as food. A few seeds, such as the castor bean, cotton seed, and corn, store a good deal of fat and are often pressed to give an edible or

medicinal oil. The lean meat of animals is particularly rich in proteins, as the fatty parts are in fats, but flesh is poor in carbohydrates.

The enormous importance of the industries which are producing these supplies — these great quantities of stored plant food — can scarcely be overestimated. In times of peace as well as in war the quantity and availability of this surplus food is of greatest significance in determining a nation's welfare.

338. Use of food by plants. If the stored food is not used by men or removed in some other way, the plant will finally use it in its processes of growth. When a seed sprouts, for example, it is several days before the little plant pushes through the ground and the chlorophyll is formed which enables the plant to utilize the carbon dioxide of the air. During this time the living material and the cell walls of the stem and roots are made from the stored material in the seed. We know that in the sprouting seed the reserve foods are first made soluble and diffusible (digested) by the action of enzymes, but the wonderful process by which these simple substances become a part of the living material of the cells (protoplasm) is still a mystery. The term "assimilation" is used to cover the constructive process by which new cellular material is made either from reserve material in a seed or from materials manufactured by the plant in the processes of photosynthesis and protein synthesis. The process of assimilation is undoubtedly similar to the process in our own bodies by which the food which is digested and carried by the blood to the cells of the body becomes a part of the cell.

339. Assimilation and respiration. It will be worth while here to contrast assimilation and respiration. Assimilation is a process by which more protoplasm is constantly made from simple chemical compounds, and it is therefore a constructive process. Respiration is a destructive process by which protoplasm and compounds closely associated with it are destroyed and the energy which they yield is made available.

The whole matter may be represented as like the slope of a hill. We begin at the bottom with carbon dioxide, water, nitrates, etc., and by means of photosynthesis, protein manufacture, and assimilation we ascend to the highest point — protoplasm; the descent on the other side is represented by respiration, which reduces the protoplasm and compounds closely associated with it to carbon dioxide, water, nitrogen compounds, and other decomposition products.

CHAPTER XXIX

THE UTILIZATION OF FOOD IN ANIMALS

340. Questions for Discussion. **1.** Why is it necessary for attention to be constantly directed to sources of food for men? **2.** What would be the result if all the world's cereal crops should completely fail for one season? **3.** Why is it that in the wake of armies when they have advanced, one of the first things done is to try to get the devastated soil planted with some kind of agricultural crop? **4.** Which is more dependent upon the other, city or country? Why? **5.** Why is it highly important to have a balanced ration for men and domestic animals? **6.** Is the chief purpose of mastication of food that of breaking it up so that it can be swallowed? **7.** In human mastication what function is performed by the saliva? Is it of any value to give the saliva prolonged time to act? **8.** If food is swallowed hastily can the saliva do its part of the work of digestion as well after the food is swallowed as before? **9.** In what ways do the secretions of the liver and pancreas affect the processes of digestion? **10.** How does the digested food find its way into the circulatory system? **11.** Is it important as a phase of nutrition that food should be palatable? Should we be nourished by good food just as truly if it were not pleasant to the taste as if it were pleasant? **12.** Rub the tongue quite dry, then place some sugar on it, and see if you taste the sugar. **13.** Close your eyes and allow someone to place coarse sugar or fine salt on your tongue and see whether you can detect at once which you have.

341. Food a universal necessity. The quantity of food consumed by man and the domestic animals is very great indeed, and a supply of food is at all times a matter of the greatest importance. In times of war the food supply is often spoken of as a means of endurance. Lack of food has caused the surrender of cities, defeated armies in the field, changed the policies of nations, and caused the loss of thousands of lives. In olden times famines were of common occurrence, because when food failed in certain places there were no means of

securing it from localities where it was more abundant. Modern transportation systems have changed conditions so that in times of peace a famine can hardly occur except in an undeveloped country.

Sometimes the cost of food is so great that many people cannot afford to buy enough of it. The population of the United States has been increasing more rapidly than the production of food, and this, together with the Great War and other causes, results in prices exceeding any previously known.

342. The purpose of food. Many people do not consider why they take food into their bodies. Doubtless, if asked to give an immediate answer to the question as to why they eat, many would say that it is to satisfy hunger. In a way such an answer would be correct, but it would be superficial. Indeed, if that were the only reason, it would not be worth while to expend all the time and trouble that we do in eating. One may discipline himself in a few days, as has often been done by men who have fasted, to such an extent that hunger no longer troubles him seriously. If this were continued, death would ensue, though the person, it is said, might not be conscious of hunger for some time prior to his death.

We eat in order that growth may take place, in order that waste protoplasm may be replenished — above all, in order that energy may be brought into the body and used in doing its work, whether it is the beating of the heart or riding a bicycle. Growth and replenishment of protoplasm and the release and use of energy are, therefore, the real purposes of nutrition.

343. The human body a machine. The human body is often compared to a machine because it can do work. It is infinitely more wonderful than any automobile, however, not only because it can take itself uphill but because it grows from a small machine to a big one and keeps itself in repair. All that most of us have to do is to feed the machine the proper kind of food and observe the rules of hygiene, and the machine takes care of itself. We have little respect for

a careless chauffeur, and we should have still less respect for a person who abuses so wonderful a machine as his own body and refuses to learn the rules for its care.

344. Preparation of food for absorption. All animals except man take their food just as it is provided by plants or other animals. Man long ago discovered fire and has become accustomed to cooking all the harder and tougher parts of his food, such as corn, wheat, meat, and hard vegetables. Many foods are now subjected to manufacturing processes before they are eaten. Certain of these processes modify the flavor or improve the keeping quality, and others make it possible to cook the food in a much shorter time.

Whether food is cooked or not, it must be very thoroughly changed before it can reach the cells of the body and nourish them. Just as the starch which is stored in a seed must be changed to sugar before it can travel in the sap and help to form new cellular material in the growing embryo, so all the complex foods eaten by an animal must be changed to soluble form before they can be used by the body. These changes take place in the alimentary canal, which is composed of several sections, each of which performs one or more special functions related to the use of foods.

Thorough mastication, like cooking, helps to soften and subdivide the food, but the real work of preparing the food for the use of the body cells is carried out by chemical substances (enzymes) which are poured into the alimentary canal from various glands. The salivary glands pour into the mouth a secretion containing ptyalin, an enzyme which starts the digestion of starch. This enzyme is similar to the diastase in plants. Small glands in the stomach wall secrete an enzyme pepsin, which begins the digestion of protein. Secretions poured into the upper part of the intestine by the pancreas and liver and secretions from small glands lining the intestinal wall complete the digestion of starch and protein and effect the digestion of fat. As a final result, by the time the

food has passed a short way down the intestine, nearly all the food which can be digested has been converted into soluble substances; these pass with water through the wall of the alimentary canal into the blood and are carried to all the cells of the body. Small residues of food, consisting largely of the fibers of food which cannot be digested and of residues from the digestive juices, are swept along into the large intestine and finally voided as waste.

345. Motions of the alimentary canal. The act of swallowing is voluntary, but when food is once swallowed, it is passed along by a process that is largely automatic. The chief stimuli are the food itself and the secreted juices. Pleasant anticipation of food has a favorable effect on the whole process; extreme fatigue or emotion — such as anger, fear, or worry — may entirely stop the digestion of food and its motion along the alimentary canal.

346. Proper care of the alimentary canal. Since the alimentary canal is really a factory in which food is prepared for the use of the cells, it is very necessary that we should give it good care. Our first responsibility is to take good care of the teeth. We need them all — the flattened front teeth (incisors) for cutting, the pointed canines for tearing, and the bicuspids and molars for grinding. The dentist is a good friend. Furthermore, we should use our teeth for the purpose for which they were intended. If food is swallowed unchewed the digestive juices can act upon it only slowly, the food remains longer than it should in the alimentary canal, and after a while the person may develop chronic indigestion.

It is important to eat at regular hours and not to be continually eating between meals. The alimentary canal needs to have a rest between meals just as much as the brain needs to have a rest every night.

We should be sure that the lower end of the alimentary canal is cleaned out every day. The best ways to do this are to drink much water every day; to eat some food at every

meal which leaves a residue of cellulose, such as oatmeal, bread, fruit, and vegetables; and to go to the toilet regularly. If water is taken at mealtime it should not be used to wash down unchewed food.

Since mental states have such an effect on the flow of the digestive juices and on the movement of food along the alimentary canal, everyone should try to see that mealtimes are as pleasant as possible. If one is very tired, it is often better not to eat until after one has rested.

347. Transportation of food to the cells. The food, after its complex preparation in the alimentary canal, passes with water through the intestinal wall into the small capillaries of the circulatory system and is carried to all the cells of the body. The circulatory system consists of a series of branching tubes through which the blood is forced by the heart. The blood flows away from the heart through arteries, which divide and redivide into smaller and smaller branches. They terminate in many extremely small tubes, known as capillaries, which are interwoven so as to constitute a fine network. These capillaries are directly in contact with the cells of the body. The capillaries unite and form the veins which finally, as large veins, lead back to the heart. So rapid is the movement of blood that it is accurately estimated that a given particle may sometimes leave the heart, make its round to one of the more distant parts of the body, and return to the heart within half a minute.

348. The heart and circulation. The branching of the circulatory system is much too complex to show in any single picture, but the accompanying diagram shows the kind of branching. It is to be remembered that every cell in the body is reached directly or indirectly by a capillary. The diagram also shows the relation between the circulation through the lungs and through the rest of the body. The right side of the heart pumps the blood through the lungs. The blood is returned to the left side of the heart, which

then pumps it through the rest of the body. It is brought back again to the right side of the heart. Each side of the heart consists of two chambers separated by a valve. The auricle is a thin-walled chamber which receives the blood on

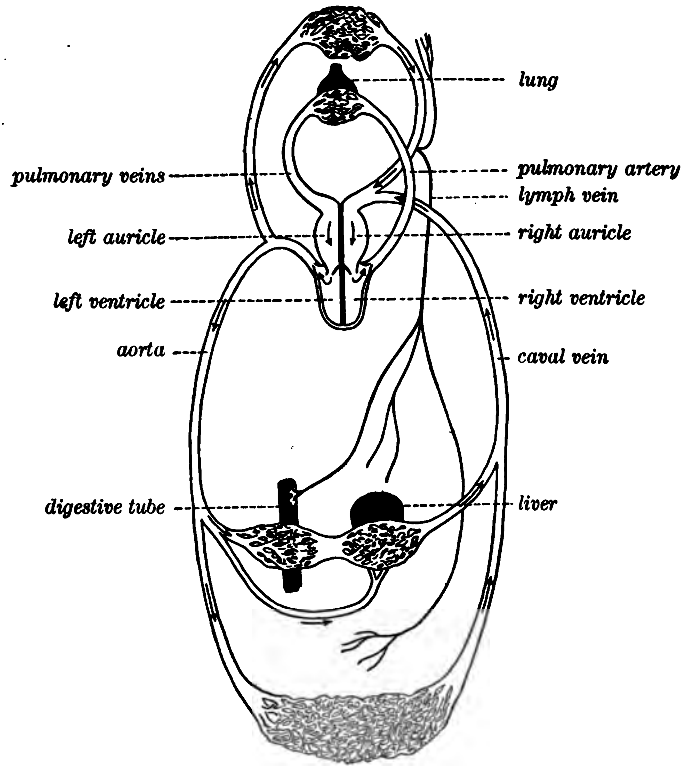


FIG. 161. Diagram of the course of the blood through the body

its return to the heart. The ventricle is thick-walled and sends the blood out by a powerful contraction. (Trace the course of the arrows in diagram 161.)

The blood is the great carrier of the body. It takes food from the alimentary canal to every cell in the body, and it also brings oxygen from the lungs to every cell in the body.

The blood is able to carry oxygen because the red blood corpuscles, which are very numerous, contain a chemical substance — hæmoglobin — which combines with oxygen and later gives it up to any cell where it is required. The blood not only brings to the cell food and oxygen which are necessary for its life processes but also carries away the waste products from the cell. Carbon dioxide is carried away from the cells to the lungs; urea and other substances are carried to the kidneys and excreted. The water which is lost to the body in the breath, in perspiration, and in the excretion of the kidneys is also carried by the blood.

349. Digestion and exercise. The blood vessels under pressure from the arteries expand or contract and thus regulate the volume of blood flowing through an organ. During the height of digestion the capillaries in the intestinal wall are very much dilated and the proportion of blood flowing through them is therefore large. This explains why it is so hard to study after a full meal. There is not enough blood flowing through the capillaries of the brain to make it alert and active. During digestion excessive exercise retards the digestive processes. When the muscles are being used, the blood flow through them is large and there is not enough blood in the intestinal capillaries.

Wild animals which feed at irregular intervals and eat to distention when they do feed usually become quiet and often sleep for some time after feeding. In such cases the chief activities of the body are for a time centered about digestion and the circulatory distribution of food. Animals which feed oftener and eat smaller quantities — man, for example — may safely proceed with some sort of mild exercise after eating.

350. Food and work. A large part of the food we eat corresponds to the gasoline in the automobile. It combines with oxygen in the cells of the body and releases energy by which we do our work. This is the process of respiration, the same process that was described as taking place in plant

cells. People often think of respiration as merely involving the process of taking air into the lungs and then expelling it. That process is breathing, and is merely the preliminary part of respiration. The animal cells are able to obtain energy from carbohydrates, fats, and proteins more or less interchangeably.

The more work a person does, the more food he needs. Work in this sense means something done by the muscles, and may be either work or play in the ordinary sense. Lumbermen and boys of high-school age frequently eat about the same amount of food. If a person spent all his time in bed he would still be doing a good deal of work just because he was alive. When we are resting, the heart contracts about seventy-two times a minute, we breathe about sixteen times a minute, and we make many motions of which we are unconscious. If a lumberman broke his leg and so had to sit quietly, he would need about a third as much food as when working. The weight of the body ordinarily furnishes a good test of whether the right amount of food is used (see fig. 162). An adult of normal weight for his height who maintains his weight over a long period of time evidently has about the proper amount of food. A young person should increase steadily in weight, but this should be good muscle and bone and not all fat.

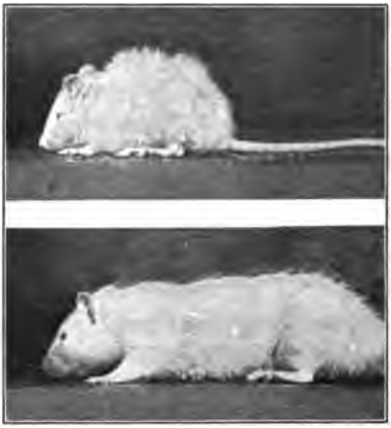


FIG. 162. Effects of poor and good nutrition

The upper photograph is of a rat at the age of five hundred and five days and after prolonged stunting from insufficient food. The rat weighed 53 grams when the upper picture was taken. The same animal when being fed a suitable quantity and quality of food gradually increased in weight until at the time the lower picture was taken it had reached 205 grams. Photographs by Professor Lafayette B. Mendel

351. Food and body temperature. In the chapter on mechanical energy we learned that when work is done, a part of the mechanical energy is converted into heat. This is true also of the chemical energy of the cell. When food combines with oxygen to release energy to do work, a large amount of heat is produced. This is the heat which keeps us warm. Often in summer the heat produced is more than we need, especially if we are working hard. The body gets rid of this heat by evaporating a large amount of water from the skin (perspiration). In winter, on the other hand, we would often be cold if we did not put on more clothing to prevent the loss of heat, or exercise vigorously so that more heat will be liberated.

352. Food and repair. Another use which the body makes of food is for repair. Changes take place in all the cells of the body just because they are alive, and we need a constant small allowance of many kinds of repair material. We also need material for body-building during the process of growth. A growing child is constantly forming more bone, more muscle, more blood, more nervous tissue. For these processes we use the same name which we use in describing similar processes in the plant cell — assimilation. Nearly everyone knows that we must assimilate some protein in both repair and growth, but we need many other things also. We need lime and phosphorus for every cell and especially for bone formation. A small amount of iron is needed for every cell and to make the hæmoglobin of the blood.

It would make a long story to describe all the materials which are needed for repair and growth, but it is not difficult to give a few rules by which food may be chosen to contain all the necessary substances. Most foods which we eat are very complex mixtures and serve several purposes in the body. It is therefore important that we study the kinds of foods and determine the sources from which they may be secured most economically.

353. Proper balance of foods. We should eat every day something made from cereals (Food Group I) — either breakfast food or bread or rice or macaroni. Fruit (Food Group III) and vegetables (Food Group IV) should each be eaten at least once a day. Most young people like fruit, but many do not like vegetables and refuse to eat them. Fruit and vegetables are important because they help to keep the alimentary canal in good condition, and also because they contain a number of substances very important for growth, such as lime, phosphorus, and iron. Everybody needs some fat. If milk is used, a good deal of fat is furnished; some meats contain much fat, but most people, especially thin people, need to eat some fat (Food Group II) in addition to that from these sources. Fat gives more energy than any other food when it is burned in the body, and most people who need a good deal of fuel, such as soldiers, lumbermen, etc., eat large quantities of fat. We should eat daily some food rich in protein, such as milk, cheese, meat, fish, eggs, peas, or beans (Food Groups IV and V). In addition to its protein, milk contains so many substances important for growth that it should be used every day by growing children. The milk which is used in cooking is just as valuable as if it were taken from a glass.

All foods furnish more or less fuel — fat the most, sugar next, and watery fruits and vegetables least of all. An eminent scientist thinks that some day we shall buy our food the way a manufacturer buys coal — according to its fuel value. If we have to economize on food it is important to know what foods in each group give the most fuel for the money, but we must not omit any important kind of food. If we remember that we should have cereal, protein food, fruit, vegetables, and fat, we shall be able to choose in each group those foods which we can afford. We must also remember that milk is essential for growing children.

354. Tea and coffee. Tea and coffee have not been mentioned so far in our discussion of food. The reason for this

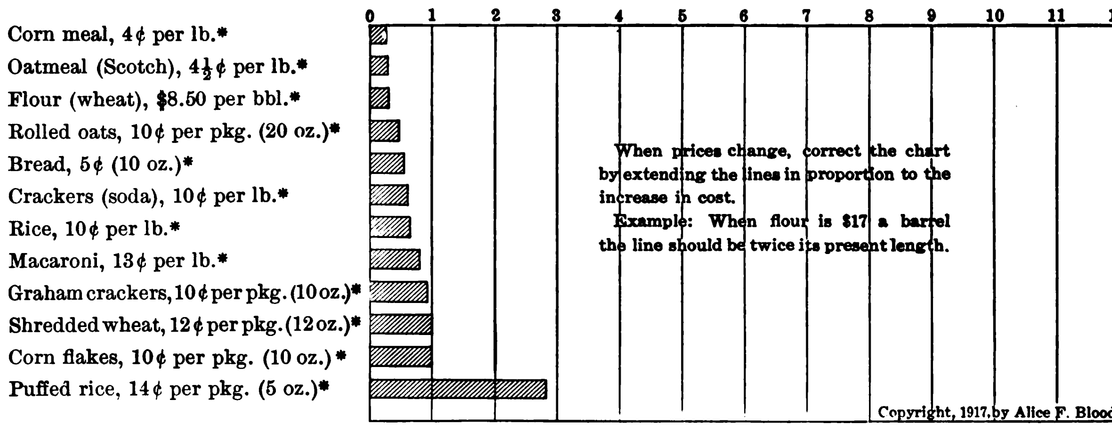


FIG. 163. Food Group I. Chart showing the relative cost of equivalent fuel portions of foods

Food for the day should include food from each of the five groups. No group should be omitted. For an economical diet choose in each group the food near the top of the list. Foods in Groups I, II, and IV which are marked with a star (*) contain appreciable amounts of protein. If these foods are used liberally they may partially replace foods in Group V. Milk should not be omitted, especially for children. If the distance between vertical lines is taken as one cent, the costs plotted are the costs of hundred-calorie portions

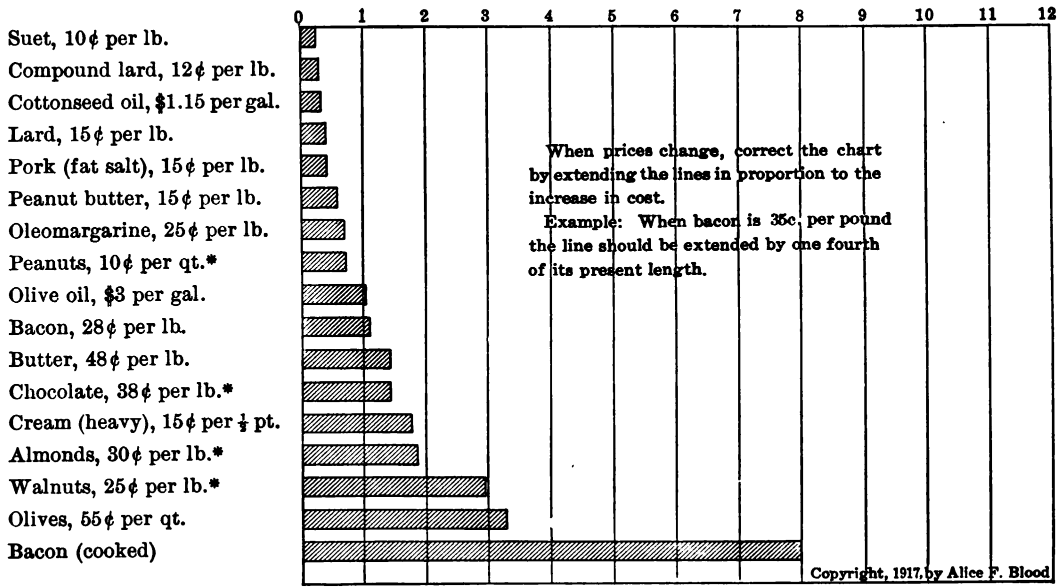


FIG. 164. Food Group II. Chart showing the relative cost of equivalent fuel portions of foods

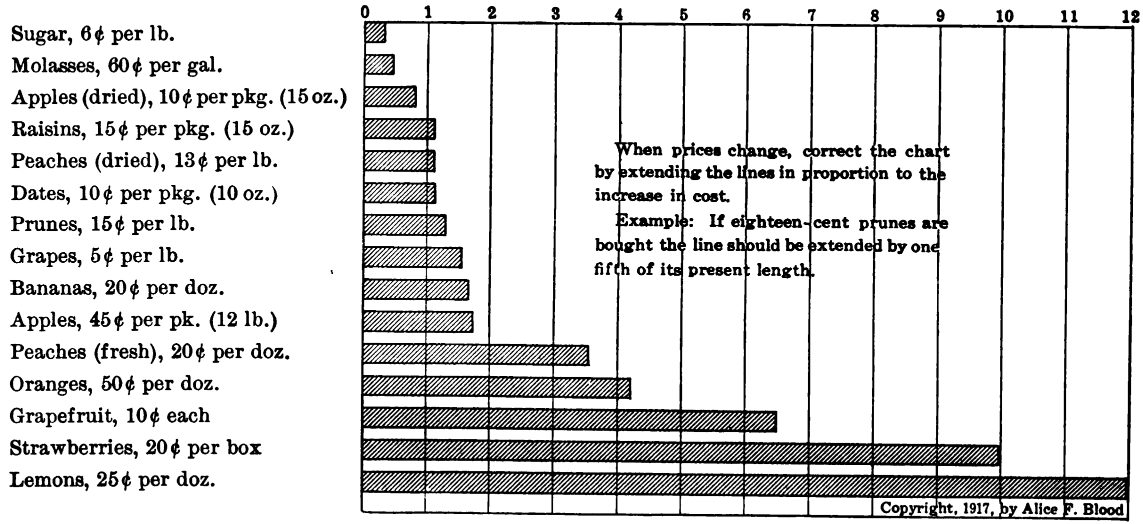


FIG. 165. Food Group III. Chart showing the relative cost of equivalent fuel portions of foods

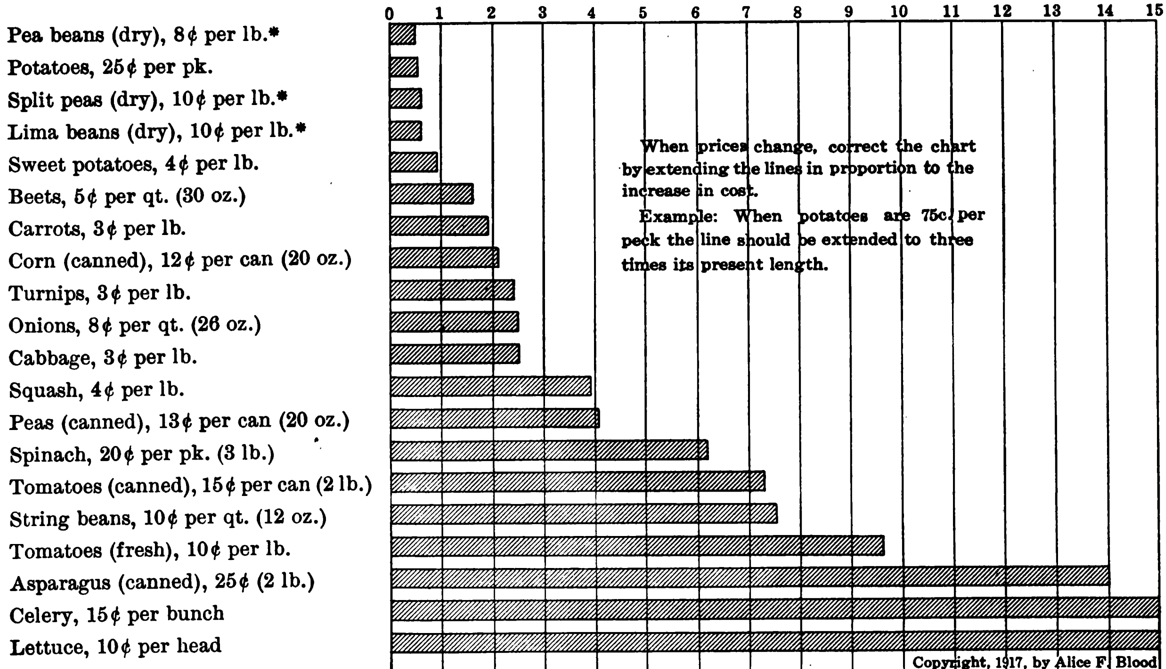


FIG. 166. Food Group IV. Chart showing the relative cost of equivalent fuel portions of foods

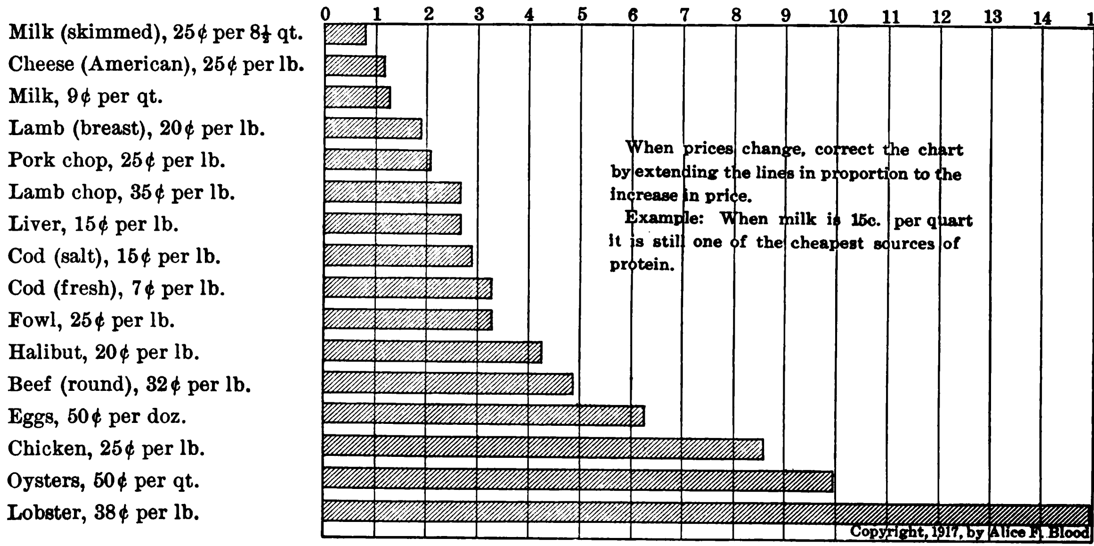


FIG. 167. Food Group V. Chart showing the relative cost of equivalent fuel portions of foods

is that they have no food value except that of the added cream and sugar. The feeling of satisfaction which they produce is due partly to the effect of heat on the stomach, but chiefly to the stimulating effect of caffeine on the heart and the nervous system. It is a serious mistake for children and young people to drink either tea or coffee. A young and spirited horse not only does not need the lash of a whip but is greatly irritated by it, and so it sometimes is with human beings and coffee. Even adults should use these beverages with moderation or abstain from their use altogether if their effect is marked. When an emergency arises, such as the necessity of keeping awake all night or of working when one is very tired, a cup of strong tea or strong coffee may be an invaluable resource. In its lists of instructions for first aid to the injured the Red Cross recommends strong hot coffee as the very best stimulant. The economic importance of these beverages is indicated by the facts that in 1915 there was used in the United States 1,126,041,691 pounds of coffee and 96,987,942 pounds of tea.

Cocoa differs from tea and coffee in being much less stimulating. This is a suitable beverage for children if it is not made too strong and is made with milk. Doubtless many older persons who drink coffee would be benefited by using cocoa instead.

355. Is alcohol a food? Alcohol is sometimes considered a food because it can be burned or oxidized in the body to liberate energy. It seems hardly safe, however, to describe as a food a substance which has a marked depressing effect on the body, similar to that of the hypnotic drugs such as ether and chloroform. Alcohol was sometimes used as an anæsthetic before the days of chloroform. In speaking of the properties of foods one noted physiologist has said: "Neither the substance itself nor any of the products of its transformation in the body must be injurious to the structure or activity of any organ. If so, it is a *poison* and not a food." One

of the most harmful effects of alcohol is its injury to the nervous system; but besides this it is thought to aid in the production of some forms of diabetes and gout. Because of these facts alcohol is classed as a poison rather than a food.

356. Does alcohol make the body warm? We *feel* warm on a hot day and cold on a cold day when in reality our bodies are practically at the same temperature, namely, 98.6° F. On a warm day the smallest blood vessels near the surface of the body are dilated and contain much blood, and we feel warm. Conversely, on a cold day these blood vessels are contracted and contain little blood, and we feel cold. Alcohol, when taken into the body, affects the nerves controlling these small blood vessels in the skin in such a way that they are dilated. This results in a rush of blood to the surface of the body, which causes a warm feeling. What is actually happening is that the body is being unduly cooled because so much blood is brought near the surface. Because of this fact a person under the influence of liquor may freeze to death under conditions which a sober person would survive. Abstinence from all alcoholic drinks is a rule among arctic explorers.

357. Alcohol and efficiency. The shocking consequences of taking alcohol in excess are evident to anyone who has seen an intoxicated person. The effect of taking alcohol in so-called "moderation" is less evident but no less certain. It is one of the most insidious dangers of alcohol that it is a habit-forming drug which may blunt the perception of the user until he no longer judges properly or cares whether his use of alcohol is moderate or not and often loses his attitude of responsibility for his work. This is one reason why so many business organizations, including most railroad companies, will not knowingly employ anyone who drinks even moderately.

Another reason why some business men will not employ a man who drinks is that alcohol, even in small amounts,

does not stimulate, but depresses. Even a small amount makes a man less accurate, less rapid in his movements, and less reliable in his judgments. A company working conscientiously to give the maximum wages and to shorten the day of work cannot afford to employ a staff which is constantly working at less than its best efficiency. A traveling salesman needs all his wits if he is to do his best for the company he represents. A soldier needs a clear brain if his marksmanship is to be accurate. In tests which were recently made in Sweden it was found that a group of soldiers who averaged twenty-three hits out of thirty shots on days when they had no alcohol averaged only three hits out of thirty shots on days when they had moderate amounts of alcohol. It is one of the curious effects of alcohol that a person's judgment in regard to his own accomplishments is not reliable. A person who drinks alcohol seems to himself to be "stimulated," to be thinking more clearly, and to be working faster and more accurately, when the results show that the opposite is the case. A man slightly under the influence of liquor may seem to himself very witty, when to the sober onlooker he seems merely silly. Alcohol removes those inhibitions which are the safeguards of proper conduct.

358. Alcohol and long life. If alcohol be a food, then the continued use of it should in no wise shorten the life of the one who uses it. Life-insurance companies refuse to insure the lives of drunkards, and by keeping careful records have found that moderate drinking shortens life.

359. Alcohol and the nation. There have been people for many years who have been fully conscious of the damage caused by the use of alcoholic beverages. In the last few years a large amount of clear thinking has been done not only by social workers and physicians, who see the effect of alcohol on the individual and his family, but also by the leaders of industry, who are coming to realize the frightful waste to industries and the state for which alcohol is

responsible. An increasing number of people believe that alcohol is such a deadly enemy of society that its sale should be forbidden exactly as are the sales of other habit-forming drugs like cocaine and opium. In this country many states have already passed laws prohibiting the manufacture and sale of alcoholic beverages of all kinds, and scarcely a year passes without new states being added to the list of those that are dry. Recently the United States National Congress passed an amendment to our constitution prohibiting the manufacture and sale of alcohol as a beverage. This amendment, in order to become a law, requires the ratification of thirty-six states.

The Great War has made people think about efficiency as they have never done before. Russia led the Allies in prohibiting the manufacture and sale of vodka, a distilled liquor of high alcohol content. In certain parts of Russia the sale of wine and beer is prohibited. In England the manufacture and sale of beer is still permitted in spite of its recognized evil effects. David Lloyd George, the prime minister of that country, has been quoted as saying of the war: "We are fighting Germany, Austria, and Drink, and so far as I can see, the greatest of these deadly foes is Drink."

360. Alcohol and the food supply. When we face the problem of a world shortage of food, alcohol appears in a still different light. In the year 1915 there were consumed in the United States more than 32,000,000 gallons of wines, almost 2,000,000,000 gallons of malt liquors, and more than 100,000,000 gallons of distilled spirits. It seems a social injustice to permit our grains and fruits to be converted into these drinks at a time when people are starving for food. It is estimated that the grain which could be saved in a year by national prohibition would be sufficient to feed an army of 7,000,000 men for a year. Such estimates may or may not be entirely accurate, but that enormous quantities of food would be saved if manufacture of alcohol for drink

could be stopped is clear. Since too little food means bodily and mental inefficiency, since self-respect and the respect of others are assets indispensable to good work, and since sound brains and clear intellects are at a premium, surely alcohol must be recognized as a liability which modern intelligent people will omit from their lives.

CHAPTER XXX

HYGIENIC ASPECTS OF NUTRITION

361. Questions for Discussion. **1.** Compare the human body with a steam engine in respect to (1) materials to be fed to it; (2) source of materials used; (3) necessity of consumption of materials; (4) how energy secured is used; (5) products; (6) care needed to keep it in working condition; (7) chief sources of wear and tear; (8) what becomes of broken-down organism. **2.** What are the effects of putting too much food into the body or swallowing it too hastily? **3.** What is the proper variety of foods? Does your own diet compare favorably with what is regarded as a properly balanced diet? **4.** It is quite possible to develop an appetite in such a way that only a part of the things needed in a balanced ration are desired. Is your appetite so developed? **5.** Are substitutes for well-known foods (such as cottonseed fat for butter fat) injurious to us? Why do we sometimes object to these substitutes? **6.** Secure your state pure-food regulations and report on them in class.

362. Needed care — pain a danger signal. It is frequently said that most human ills have their origin in the nutritive system. After learning what alcohol can do to us we often feel that it is in a class by itself as a source of danger. In certain respects this is true, but constant attention must be given to our ordinary foods and their uses if good health is to be secured. The human body is such a complicated mechanism that intelligent care is essential to its best use.

Few people really understand how a locomotive operates, though most people are interested in learning about it. The human body is a machine that is far more complex than the locomotive, and a machine which each of us must have a hand in running. We have such natural appetites as hunger and thirst and such pains as headache and stomach ache, which tell us superficially about the needs of the human

machine. But sometimes when these natural guides become intense enough to demand our attention the machine is already in trouble and its efficiency impaired or threatened. If a locomotive engineer did not supply his machine with water until the boiler was nearly empty, it would then be dangerous to add the water. In the human body severe pain is ordinarily an evidence that difficulties have existed for some time. Pain is usually a distress signal. The body as a machine for using energy will give most efficient service if it is treated in such a way that it is neither overfed nor underfed and that the food is in the best condition for use by the human machine.

363. Thorough mastication. In the preceding chapter some of the reasons for mastication were stated. Indigestion may be caused by improper mastication, and some students of the human machine believe that many intestinal troubles are due directly or indirectly to this cause. Large pieces of food are not readily digested in the stomach and intestine.

While the food is being broken into small pieces in the mouth, the saliva is mixed with it and makes it partially or wholly liquid, thus facilitating its digestion by other digestive secretions. Furthermore, so much of our food is carbohydrate (starch, sugar, etc.) and is digested by the saliva that the importance of thorough mastication is easily seen. If fruits, bread, pastries, candy, etc. were kept in the mouth and thoroughly mixed with saliva before swallowing, there would be fewer cases of indigestion.

364. Heavy eating. Poor mastication of food is usually associated with overeating. This may result partly from the fact that poorly masticated food does not readily produce a feeling of satisfaction. Since this is true, a rapid eater continues to eat until he has swallowed an amount of food in excess of what he would have desired if he had masticated thoroughly and satisfied his hunger in a proper way. Not only is this extra quantity of food present in the digestive system

but the starchy foods which should have been digested in the mouth, in part at least, add an extra burden to the work of the starch-digesting element of the pancreatic secretion; even here they may not be thoroughly digested and so may not all be used in the nutrition of the body. One is in no danger of being too thorough in the mastication of his food.

365. Amount of food. The discussion and food charts presented in section 353 gave definite information regarding the kinds of foods, a list of substances from which different kinds of foods may be secured, and a basis of comparison of the costs of foods from the different substances listed. Since the digestive system is so organized that it can digest carbohydrates, fats, and proteins, and since all these are needed for proper nutrition, it is of much hygienic importance that these foods be used in as nearly proper proportion as can be arranged. If a person eats but one kind of food he is not properly nourished, and the work of digestion is not distributed to the whole digestive system. The appetite may serve as a partial guide to the kind of food needed, but it is not fully to be trusted, partly because we are often uncertain concerning the exact kind of food we are hungry for and partly because our habits of eating often cultivate appetites that may not call for exactly what we need.

Experiments have been performed in the effort to determine what amounts of food are necessary for persons engaged in active work. It is stated roughly that active workers require from 100 to 125 grams of protein food per day; but it has also been shown that such workers as soldiers, teachers, and athletes may work effectively for at least several months upon less protein food; that is, from 40 to 50 grams per day. Similarly, it has been stated that a representative distribution of foods for the composition of an ordinary day's diet may consist of protein, 118 grams; fats, 56 grams; carbohydrates, 500 grams. It must be kept in mind, however, that the above figures are merely suggestive. So much

depends upon the kinds of materials from which the protein, fats, and carbohydrates are secured, and upon such factors as the condition of the body and nature of exercise, that statements of definite quantities cannot be considered as an entirely trustworthy guide. It is highly important to make certain that the day's diet includes foods from the various sources — vegetables, fruits, and milk, as well as meat and bread.

It is true, however, that the amounts of food needed may vary greatly according to personal habits, the kind of work in which one is engaged, and the climate. Men engaged in hard physical work in cold climates demand larger quantities of food than here given and a larger proportion of fats, while people in tropical regions may work better with smaller amounts of fats and more carbohydrates. In the same way, the quantity of water needed varies in different climates and with different occupations.

366. Contaminated food. Nearly all kinds of food may become the growing place for bacteria or other organisms that will, if allowed to continue to grow, finally bring about the decay of the food. A review of what was said on this point in connection with the discussion of the bacteria and molds (Chapter VIII) will prove helpful. Sometimes these decay-producing organisms are dangerous to human health and sometimes they are not. For example, the blue molds that grow in Roquefort cheese, or the bacteria that ripen other kinds of cheese, are not unwholesome and, indeed, are the causes of the desired flavors of the different kinds of cheese.

Preservatives are sometimes used to prevent the decay of foods. Small amounts of formalin, benzoate of soda, or other chemicals may be put into the liquid foods as milk, and will prevent decay; but while from superficial examination such foods may appear to be good, they may at the same time contain enough of the preservative to prove injurious. When milk under exposure to the temperature of ordinary air

does not begin to sour within twenty-four hours, it is time to have it examined chemically to determine what preservative it may contain. Refrigeration and pasteurization are the safest methods of preserving milk, and these are effective for only a day or two, since they retard but do not prevent the development of bacteria.

Various kinds of chemicals are used in the preservation of meats. These chemicals are sometimes of a poisonous nature. In most cases, however, preserved meats are injured more by excessive quantities of relatively harmless preservatives. An excessive amount of salt hardens the fiber of the meat and destroys its normal taste. Salt, sugar, etc. are used to cure meat because they take up water so rapidly that bacteria are killed by the extraction of the water from the bacteria. The older practice of smoking meat gave a coated surface of creosote in which destructive organisms could not live.

367. Food and filth. There is no inherent reason why small particles of earth upon our food should be injurious to our bodies, though they are always unattractive, but dirt of any kind upon our food suggests the possibility of the presence of living organisms that may prove injurious. It is more important, however, to know that our food has been handled only by persons who are free from disease germs than to know that the food is not conspicuously dirty. Apples which are shipped in barrels may have small particles of dirt adhering to them and may not appear so attractive as when highly polished, but if they are polished by the use of a soiled and bacteria-laden cloth, they may thereafter be infinitely more dangerous as food than when first removed from the shipping barrel. Obviously, great care should be exercised to determine whether vegetables and other foods have been handled in cleanly ways. A systematic examination of the vegetable markets, with reports and discussions in class, will prove instructive. Fortunately, thorough cooking will destroy bacteria, and unless one is reasonably sure that there is no

contamination, thorough cooking should always precede the introduction of food into the body. The body is a machine, and food is the material that builds it up and supplies the energy to run it. Filth and disease bacteria interfere with the normal work and efficiency of the machine.

368. Circulation and nutrition. The rôle of the circulation in carrying digested food to the tissues has already been discussed. It must be clearly understood, therefore, that anything which makes the circulation abnormal will affect nutrition. In most adults the heart beats about seventy-two times per minute. In children and youths the rate is likely to be higher, while in old people it may be lower. By placing a finger upon the inside of the wrist one can usually feel the pulse, which tells accurately how many times per minute the left ventricle is contracting. Count your pulse beats during each of several minutes and determine what the normal average is.

During severe exercise increased release of energy takes place, and there is increased demand for oxygen and food. This results in increased heart action. In some cases of severe illness during high fever a similar demand is made, with a similar increase of heart action. Prolonged increase above the normal rate means excessive wear upon the parts of the human machine that are affected. A brief period of this unusual stimulation is not necessarily harmful and may often be decidedly helpful.

369. Breathing and nutrition. Experiments similar to those suggested in connection with circulation will enable one to determine that the normal breathing rate is about sixteen times per minute and also that violent exercise increases the rate. The tissues demand oxygen, which is secured from the blood. The blood's supply of oxygen is replenished in the lungs, where the waste carbon dioxide is removed. When an increased amount of blood needing replenishment and purification is hastened through the lungs, there is need of

more air in the lungs. It is the demand for oxygen in the tissues which stimulates an increase in the rate of breathing. Any boy or girl who has run until exhausted knows that at such a time the body needs more air than usual. If a mouse or other animal is placed under a bell jar and the air is exhausted, the animal breathes rapidly and with the same violent efforts to get air that are shown by an animal that is exhausted from exercise.

Any exercise that tends to increase the air capacity of the lungs increases one's ability to supply his blood with oxygen and to remove waste products from the blood. Deep-breathing exercises are of great importance in increasing the lung capacity. Vigorous exercise is helpful to many persons, since such exercise often compels them to breathe deeply — a thing which they should practice whether compelled to or not.

It needs no argument to show that pure air is better for the body than impure air. The nasal passages are so constructed as to assist in screening out floating particles, as bacteria and dust. Persons who breathe through the mouth are likely to accumulate dust in the passages leading to the lungs, and in large cities with dusty air such persons may accumulate enough dust to prove a menace to the work of the lungs. Collections of dust may become sources of irritation and may be the starting points for the growth of disease germs, such as those of tuberculosis. Air that is breathed inward through the nose in winter time is warmed before entering the lungs, but if taken in through the mouth its temperature is changed but little before reaching the lungs and may chill the lung tissue. "Mouth breathers" should consult a physician to determine whether there is any structural reason for their practice. If not, careful attention will enable them to change the habit to normal breathing.

CHAPTER XXXI

REPRODUCTION IN PLANTS AND ANIMALS

370. Questions for Discussion. **1.** If a yeast plant can itself become full grown and produce one new yeast plant in twenty minutes, and this rate continues for twenty-four hours, how many yeast plants will be produced from one plant in that time? **2.** Does the rate of reproduction of yeast plants have anything to do with the rate at which fermentation by yeast occurs? **3.** How long does it take for a forest tree to reproduce itself by a tree as large as the old tree? **4.** If possible, secure frog's eggs or toad's eggs and allow them to develop in a dish of shallow water. Trace day by day the stages in development. **5.** In what respects is reproduction by eggs similar or dissimilar in birds and flowering plants? **6.** What common farm, garden, and house practices with plants depend on vegetative reproduction? **7.** From your state agricultural experiment station secure a bulletin on propagation of plants by cuttings and by grafting, and if possible follow the directions given in some home experiments. **8.** Are you the more sure of securing the desired kind of cultivated fruits when growing them from cuttings or from seeds? Why?

371. The meaning of reproduction. Thus far our discussions of plants and animals have dealt with problems in nutrition. In many ways those problems are of the greatest importance. But no matter how well nourished a plant or animal may be, its kind will cease to exist on the earth unless there are means by which new and younger individuals can be produced. The process by which younger individuals are produced is known as reproduction (which means "producing again").

In the bodies of plants and animals the cells divide, each cell forming two new cells from one old one. This is reproduction of cells. In most plants and animals increase in number of cells and the enlargement that results is called

growth, and not reproduction. Cell division results in reproduction in the case of one-celled animals and plants, as in the bacteria.

372. Reproduction of the yeast plant. The yeast plant consists of a single spherical or oblong cell (fig. 168). It has a simple wall, within which are the living substances that constitute the protoplasm. Yeasts get their food material from the solutions in which sugar is dissolved, and in doing so partially decompose the sugar; this partial decomposition results in the production of alcohol. But when nutrition is abundant the yeast plants enlarge and soon begin the production of new plants. First there may be noted a small, budlike outgrowth on one side of the parent plant. This bud enlarges for a time and finally becomes separated. The separated bud is a new yeast plant, and after a brief period of growth it may repeat the budding process by which it came into existence. Indeed, sometimes a large bud, even before it becomes separated from the parent, begins to form a small bud for the production of the third plant in the series.

FIG. 168. Yeast plants

a, a plant from which a bud has begun to grow; *b* and *c*, plants, each of which has two buds. Greatly enlarged

Budding represents one of the simplest kinds of reproduction. This is known as vegetative reproduction, because reproduction is accomplished by means of the ordinary nutritive, or growing, part of the plant. Many simple animals are reproduced in a similar way.

373. Reproduction of pond scum. Almost everyone has observed the common green "pond scum" floating on the surface of water or submerged. Some of this consists of plants which are very beautiful when seen under the microscope. They are silky threads composed of large cells

joined end to end. Sometimes a threadlike plant is broken into two pieces, when each piece may continue to grow as a new individual. This process is vegetative reproduction.

Sometimes two of the pond-scum plants which are near one another perform quite a different kind of reproduction (fig. 169). From two cells, one in each plant, there grow two tubular outgrowths. These grow toward one another and unite their tips in such a way as to form a continuous tubular passage between the cells. When this has been done all the living substance or protoplasm from one cell passes through the tube into the other cell. The two masses of protoplasm unite, and the mass thus formed becomes very compact and a heavy wall develops closely about it. The old cell walls decay, and the new spherical or oval cell goes to the bottom and passes through a resting period which may last through the winter

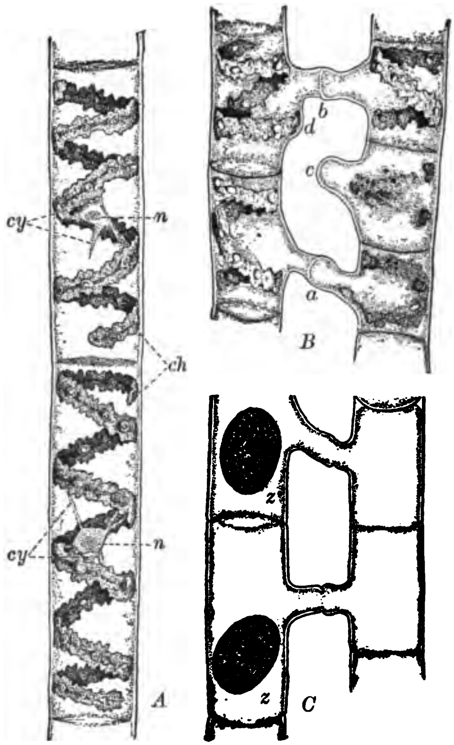


FIG. 169. A pond scum

A, two vegetative cells showing the form of the cell and of the spiral chlorophyll band (*ch*), also the nuclei of the cells (*n*), and the granular part of the protoplasm (*cy*); *B*, cells showing the beginning of the union of the tubes (*a* and *b*), and tubes which have failed to unite (*c* and *d*); *C*, completed spores (*z*)

season. At some later time the resting cell grows again, producing a new plant like those that formed it.

374. Animals and plants begin as one cell. The resting cell is called a spore, which means a special reproductive cell which can form a new plant like those that formed the spore. In forming the spore the mass of protoplasm in one cell is fertilized by having the protoplasm from the other cell unite with it. Reproduction that is brought about by having two cells unite to form the reproductive cell is called sexual reproduction. The spore thus formed may be called the sex cell or sex spore. In pond scum many paired cells of two adjacent plants may produce sex spores, and many new plants may thus be provided for.

This one sex cell begins the growth of a new pond-scum plant, and by successive divisions of the cells thus formed a many-celled plant may soon be grown. Whether a plant or animal in its adult form consists of one or of many cells, it consists of one cell at first. This is not true usually of plants or animals formed vegetatively, since cuttings, slips, and runners consist of many cells. Sexual reproduction results in the formation of one cell which through growth may become a new plant of many cells. An animal, like a plant, originates from a single cell.

375. The frog's egg. The frog or toad will serve well to illustrate reproduction among animals. Early in the spring, when frogs may first be heard in the ponds, masses of their eggs are easily found. They have the appearance of small black spheres, about a sixteenth of an inch in diameter, embedded in a transparent jelly (fig. 170). They are usually found in large numbers, since a single female may lay several thousand eggs. While the eggs appear black as they are seen in the water, it is only the upper surfaces that are dark-colored, the under surfaces being almost white.

Each of these eggs, when laid, consists of a single cell in which is stored a quantity of food material. The egg was

formed in the body of the female and expelled into the water when mature. At the same time that the female lays the eggs, the male frog expels from his body into the water

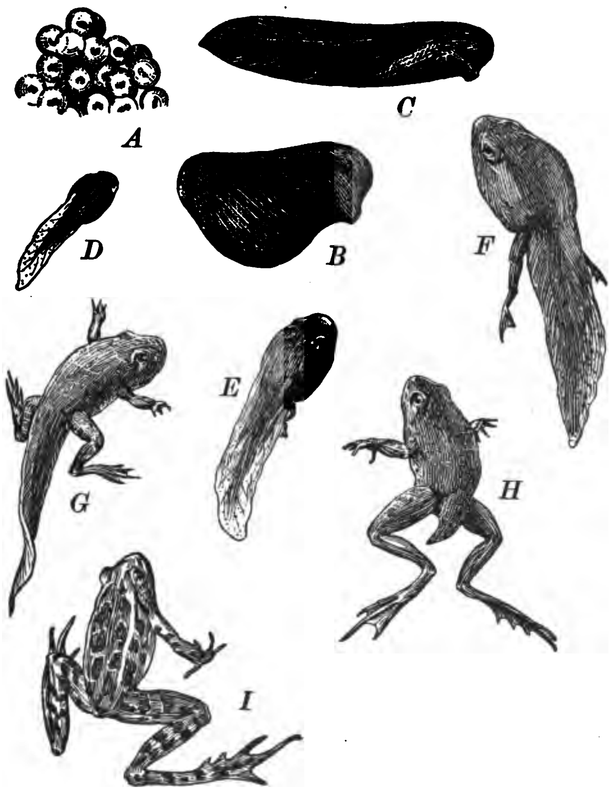


FIG. 170. Development of the frog

A, eggs; *B* and *C*, early stages of the embryo; *D*, tadpole as commonly seen; *E* and *F*, legs appearing; *G* and *H*, front legs appearing and tail disappearing; *I*, mature frog. *B* and *C* are enlarged much more than the other parts of the illustration, the others being approximately natural size

a whitish fluid which is shown by the microscope to contain great numbers of very minute cells, known as sperms. The sperms swim about actively in the water and come in contact

with the eggs. One of them may enter an egg and unite with it, thus fertilizing it. The fertilized frog's egg resembles the spore of the pond scum in that it is a single cell formed by the union of two cells.

376. Development of the egg. When the egg of the frog has been fertilized it possesses, like the spore of the pond scum, the power of growing into a new organism similar to that which produced it. The first indication of development in the frog's egg is its division into two cells. These again divide, forming four cells, and the process is repeated until the single large egg cell has become a mass of many small cells. This mass of cells elongates; mouth, eyes, and tail appear; and the young animal wriggles out of the inclosing jelly. Soon it has the complete form of the familiar tadpole.

377. The tadpole. The tadpoles are the young of frogs, toads, or closely related animals. The very numerous, small, jet-black ones are toad tadpoles. All of them resemble fish more closely than they do frogs and toads, so far as appearance and manner of life are concerned. The tadpoles live in the water all the time and breathe by means of gills, as fish do, while the mature animals live upon land much of the time and breathe by means of lungs.

During the hatching period the developing tadpoles have taken no other food than that which was stored in the egg. When they begin to swim about they become voracious feeders, eating minute animals and great quantities of green slime, pond scums, and other minute plants. They grow rapidly, and legs soon appear from the undersurface of the body. At the same time the tail decreases in size. The gills disappear also, and lungs are formed. Finally, the tadpole, with a form approaching that of the frog but with some remnants of the tail and gills, creeps out upon the land.

If eggs of the frog or toad are collected carefully and transferred to an aquarium, it is possible to follow the various stages of development at school or at home.

378. Reproduction in birds and mammals. In most of the higher animals the fertilized egg proceeds, immediately after fertilization, to the development of the beginning stages, or embryo, of the adult animal. The exception to the last statement is found in the case of those animals which lay an egg that is incased in a more or less heavy coating, like the eggs of birds and turtles, in which the real egg is a cell similar to the one already described. In these cases there is, in addition to the real egg, a large amount of food material, all of which is incased in the covering. In turtles this covering is a thick, tough, leathery wall; in birds it is thick and fragile, though it varies in its strength in different species of birds. The egg of the bird undergoes a period of incubation ranging from fourteen days (or even fewer), in the case of the smaller birds, to four weeks or more, in the case of turkeys, geese, etc. It is possible to discover the stages in the development of the embryo by examining eggs in various stages of incubation. It will be seen that at first the small embryo is reddish in color and that radiating lines of blood vessels extend from it into the food material. The developing embryo soon differentiates bone, muscle, nerve, and other tissues. In a short time the organs that are recognized in the adult bird may be found completely differentiated in the embryo that is still retained within the egg wall. It is apparent, therefore, as already noted, that a development of the embryo within the egg cell has many features in common with the development of the frog.

In the higher animals, known as mammals, and in some others the egg develops into the young animal while still within the body of the mother. In the reproduction of these animals the new individuals are born with their various structures already well formed.

379. Reproduction in seed plants; the flower. Reproduction in seed plants is in some respects quite similar and in others quite dissimilar to that of the animals. The flower

(fig. 171) is the reproductive organ in seed plants. It consists of four distinctly different kinds of structures, some of which may be absent. In a complete flower the lowest floral organs are the *sepals* (fig. 172), collectively known as the *calyx*; next above the sepals are the *petals*, collectively known as the *corolla*; above the petals are the *stamens*; and above the stamens are the *pistils*. In the flowers of some plants the pistils are absent and the flowers are pistillate. Sometimes pistillate flowers are borne on some of the branches of a plant, and staminate flowers on other branches.

FIG. 171. Flower of amaryllis

The sepals and petals are almost identical in shape and color. There are six stamens and one pistil in each flower

380. The pistil. Careful observation of the pistil will ordinarily show that there is a swollen basal portion known as the *ovary*, above which is a more elongated part, the *style*, and above that the tip portion, known as the *stigma*. By opening the ovary we may find within it small bodies, the *ovules* (fig. 173), which when mature are the seeds. When we take a very thin section

of a young ovule and examine it under the microscope, we see that in its center there is an elongated sac, the *embryo sac.* At one end of the embryo sac the egg cell is formed. Eggs may therefore be found in the flowering plant just as truly as in animals, but these eggs remain inclosed within the ovary and are not set free as in the frog.

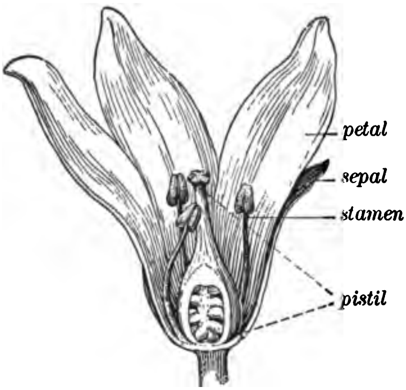


Fig. 172. Diagram of flower, showing the different parts

381. The stamen. The swollen tip of the stamen is the *anther.* Within the anther there are many small cells, the *pollen grains,* which, when the anther breaks open, are scattered in small clouds like yellow dust. When the pollen grains alight on the stigmatic end of

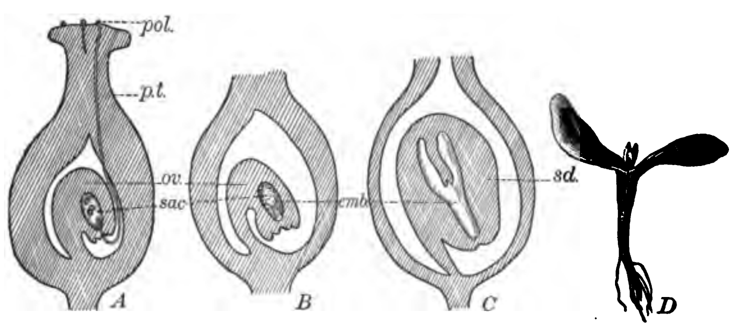


Fig. 173. Diagram to show development of young plant from the egg

A, entire pistil; *B* and *C*, development of seed; *D*, seedling plant; *pol.*, pollen grain; *p. t.*, pollen tube; *ov.*, ovule; *sac*, embryo sac; *emb.*, embryo; *sd.*, mature seed

the pistil important changes follow. From the inner wall of the pollen grain there develops a tubular outgrowth which

grows down through the stigma and style into the ovule and so reaches the vicinity of the egg. While the pollen tube has been growing down into the ovule two male cells have developed within it. One of these may unite with the egg cell, thus producing the fertilized egg. Each male cell is capable of fertilizing the egg in the ovule.

382. The embryo plant. After fertilization the egg of the plant — like the egg of the frog — proceeds at once to grow. Through cell division and enlargement one region develops into the root tip, another into the stem tip, and others into one or more leaves. In most cases, when the young plant has developed these different regions, the wall of the ovule becomes hardened and the embryo becomes dormant. This is the mature seed. It may lie dormant for a short or a long period and then grow.

Fig. 174. A peanut seedling

383. The seedling. When seeds of plants are placed in favorable situations moisture is absorbed by the young plantlet inclosed within the seed coats, and its growth is soon continued. The seed coats are burst; the root tip emerges and grows into the earth and develops additional roots. The way in which the young stem and leaves (fig. 174) emerge from the seed coats is extremely variable. In the seed of the bean there is an elongation of the stem of the young plant. This elongated stem bends in such a way as to pull the leaves out of the seed coats. In other cases, as in the sunflower, the leaves grow upright and push the seed coat into the air, dropping it only after the leaves have become well separated from one another. When the young plant has become well established

in the soil, it may continue its growth and eventually produce flowers and seeds which continue the round of reproduction.

384. Vegetative reproduction. Many plants and animals are able to have individuals arise directly from the old individual without the production of a fertilized egg (fig. 175). It is possible to cut a twig from a willow or cottonwood tree, place it in the ground, and have it grow into a new tree. One may also take cuttings or slips from geraniums, coleuses, and begonias, and plant them so that they will grow into new plants. Grapevines are started by means of cuttings. The original Concord grapevine has become the parent of millions of grapevines scattered through the civilized world, and this has been brought about entirely by cuttings from the single original grapevine or by cuttings from its descendants. This kind of reproduction of individuals is known as vegetative reproduction, because the growing plant is used directly as the means of establishing new individuals.

FIG. 175. Vegetative propagation in the raspberry

The ends of the shoots strike root in the earth and grow new plants

Different forms of grafting are in a sense types of vegetative reproduction, since they consist in making cuttings from one plant and getting them started to grow upon another plant. It will be found interesting to read agricultural and horticultural books on the subject of grafting, to determine what may be accomplished thereby.

CHAPTER XXXII

THE STRUGGLE FOR EXISTENCE

385. Questions for Discussion. **1.** It is not uncommon for high-grade hens to lay as many or more than 200 eggs each in a year. If all these eggs should be hatched and all the chickens live, and if half of the chickens should become laying hens the succeeding year for five years, how many chickens might there be as descendants of one hen at the end of the five-year period? **2.** A good many city people have become enthusiastic about moving to the country and raising poultry because they have calculated how many fowls might possibly be produced from a small number. What are some of the factors often omitted in these calculations? **3.** The rate of reproduction inherently possible if unlimited would permit one stand of honeybees to produce enough bees so that in six years Illinois would not furnish standing room for all the hives. Why cannot these enormous figures be realized in fact? **4.** How do calculations regarding overproduction help to make it clear that there is a struggle for existence? **5.** A mourning dove has frequently been known to devour more than 5000 weed seeds in a single day. Suppose, as is unlikely, that one pair of mourning doves should devour seeds at this rate for the three summer months, how many would they devour in that time? Do you think they really do devour seeds at this rate all summer? **6.** In what way may such birds help the farmer in his own struggle for existence?

386. The fight for life. If we observe a dense forest or a wheat field we see that there are many kinds of plants that are living under the shade of taller plants. Some of the shaded plants seem to be thriving, and others may show by their condition that they are not doing well. Along a country roadside also or in a vacant lot a great number of plants often start to grow in a relatively small space. By observing such a region at successive periods for some weeks it will usually be seen that fewer and fewer plants persist; and by the time

the seeds are ripe the number of plants that have matured is small indeed compared with the number that began growth at the beginning of the season.

Similarly, in a pool of water there may be many hundreds of small fish, tadpoles, and other types of animal life, but only a few mature fish and frogs.

387. Overproduction among plants. We shall get an idea of what causes the crowded conditions upon the earth if we estimate the numbers that might be produced if all the young might grow to maturity. An ordinary morning-glory plant may bear 3000 seeds in one season; indeed, such a plant often bears considerably more than that number. If each of these seeds should produce a plant that bore 3000 seeds, at the end of the second year there would be 3000 × 3000 seeds, or 9,000,000 seeds. If the second year's crop of seeds should grow in the same way, at the end of the third year there would be 27,000,000,000 seeds. Similarly, if in the succeeding years all the seeds produced should produce plants like the parent, the one plant with which we began would in five years produce 243,000,000,000,000,000 seeds. If there is an average of 20 feet of vines to each plant, the total length of the vines of the sixth-year crop would reach over 36,000,000,000 times around the earth. Since light travels 186,000 miles per second, how long would it take for it to travel the length of the sixth-year crop of morning-glory plants?

Another illustration may show in a better way the possibilities of plant production. A common kind of garden sweet corn may have 4 good ears on a stalk, 12 rows of grains on each ear, and 20 grains in each row. Therefore one ear may have 240 grains upon it, and one plant may have 960 grains. If each grain produces a new plant the next year, and this process continues for five years, the fifth-year crop will consist of 3,397,346,240,000 ears. That would be over 30,000 ears for each person in the United States, or two ears per day for each man, woman, and child for over fifty years.

Calculations which can be made in your class work will show equally well what enormous numbers of individuals would soon be produced if possibilities were allowed to become realities. Jordan says, "An annual plant producing two seeds only would have 1,048,576 descendants in twenty-one years, if each seed sprouted and matured." It is a matter of common knowledge, however, that the enormous reproduction suggested by these figures does not really occur.

388. Overproduction among animals. Animal reproduction in enormous numbers is also inherently possible. A single female codfish has been known to produce as many as 9,100,000 eggs in one year. A female salmon four years old may lay 4000 eggs. If half of these 4000 eggs grew into female salmon and produced 4000 eggs each, as did their mother, there would be 8,000,000 eggs. If we suppose that each of these 8,000,000 eggs grows into an adult salmon four years old and weighing 20 pounds (although four-year-old salmon often weigh more than 20 pounds), there would be 160,000,000 pounds of salmon in this third-generation crop. If these salmon were packed in tins and should net three fourths of their original weight, or 120,000,000 pounds, and should be sold at ten cents per pound, they would be worth $12,000,000; or if the inhabitants of a city of 10,000 people were to use an average of one fourth of a pound per day for each person, the third generation of salmon would supply this city for forty-eight thousand days, or for more than one hundred and twenty-one years.

Any given species of animal has an inherent rate of reproduction which makes enormous numbers of that species possible if we assume that this inherent rate is to have no limitations. Many an enthusiastic resident of a city has made calculations regarding the number of chickens that may grow in a small number of years from a small initial number of chickens. Some city residents have even moved into the country expecting to grow chickens in numbers comparable to these

inherently possible numbers. They have found that important limiting factors prevent the realization of their hopes.

In the first place, it is clear that there is not space enough for more than a small part of the new individuals to develop. Every open space that offers anything like reasonable living conditions for plants and animals is soon occupied by them. If the fifth-year crop of sweet corn, as calculated above, were planted as corn is ordinarily planted, it would require about 2000 times the land area of Illinois in which to plant it. If one hive of honeybees were to produce for six years as rapidly as inherently possible, and these bees should be housed in hives each of which has four square feet as its standing place, the state of Illinois would not supply standing room for the total crop of bees.

Space is too limited for any given kind of plants or animals to increase very rapidly. In a rich river bottom, in a vacant lot, in almost any place where plants and animals may get started to grow, the struggle for space is evident. In the tree tops the birds contend for nesting places (fig. 176). The English sparrow has driven many native birds away from their former nesting places. Agriculture has taken over the territory formerly occupied by many kinds of native plants and animals and has introduced other kinds of plants and animals into the old haunts of native living things.

389. Not food enough for all. The city man who would make a fortune growing chickens finds that his expense for feed is large, often so large that he cannot afford to raise chickens; and if the possible rates of increase are made real for even a short period, it is soon evident that neither space nor food is sufficient. In nature the tragedy of the shortage of the food supply is frequently seen. It would be seen constantly if it were not for the fact that one kind of living thing may serve as food for one or many other kinds. When salmon become quite abundant, other kinds of fish, or other animals, may devour them in large numbers. In our fresh-water

streams and lakes the black bass may produce hundreds of eggs and guard them until the young are hatched and are a few days old. After the mother fish has left her young, she as well as other fish may catch and devour any of them that are not so fortunate as to escape when pursued. In this way not so much food is needed for young salmon and young

FIG. 176. Struggle for existence among birds during the nesting period

In the area shown in the photograph there were twenty-four nests containing young birds or eggs. The parent birds range over a much larger area in securing food for the young birds, but it is evident that if all are adequately fed, these young and old birds are important factors in the struggle for existence in this locality. Also, since much of the food of these birds consists of insects harmful to vegetation, the birds are important economic factors. The kind of nest in each location follows: *1*, brown thrasher; *2*, orchard oriole; *3*, robin; *4*, robin; *5*, robin; *6*, brown thrasher; *7*, catbird; *8*, catbird; *9*, brown thrasher; *10*, robin; *11*, orchard oriole; *12*, cedar waxwing; *13*, robin; *14*, robin; *15*, kingbird; *16*, brown thrasher; *17*, catbird; *18*, robin; *19*, robin; *20*, robin; *21*, catbird; *22*, bronzed grackle; *23*, robin; *24*, robin. Photograph by C. W. Finley and W. B. Morgan

bass, because some of these fish have become food for others. In any kind of living things the few that reach maturity are to be looked upon as the ones that have been able to secure enough food to nourish them and enable them to grow while at the same time avoiding the catastrophe of serving as food for some other hungry animal.

390. Climatic dangers. An unexpected and severe storm in early summer leaves in its path a mass of wreckage, as

broken trees, flattened grain, upturned nests of birds, drowned nestlings, and insects killed by wind or water. The small and inconspicuous forms of life that are killed are more numerous than the larger ones. At other times sudden changes in temperature prove extremely destructive. When migratory birds are caught in snowstorms many die. The American golden plover flies southward in the autumn migration over the Atlantic Ocean from Nova Scotia to the Lesser Antilles or even to South America. Often these birds are caught in heavy storms, many doubtless perishing at sea and many being driven ashore in an injured condition. Rainstorms accompanied by hail cause the death of young birds, insects, and some larger animals, and of large numbers of plants. Excessive heat, drought, and other climatic causes are important factors in the elimination of living things.

391. Destruction by disease. A visit to a corn field or wheat field will usually enable one to discover a parasitic plant known as smut growing upon the corn or wheat. This smut secures its nourishment from the host plant. After a time it produces its reproductive spores, by means of which new smut parasites may get started on new host plants. But the host plant suffers and may be killed by the smut. Its supply of nourishment may be taken by the smut, or the smut may produce poisonous substances that severely affect the host. The smut is merely growing in its own way, but in so doing it may cause the death of other plants.

Bacteria, fungi, and some animals cause the disease and death of other living things. So universal is disease that we scarcely know what is meant by "natural death." In nature, when animals begin to get old and their bodies operate less effectively than when they were younger, they are more readily captured by food-seeking animals or are more susceptible to disease. In nature so-called natural death of animals is rarely if ever seen, since they are usually killed by their enemies or by disease.

392. The balance of life. The grass of the field is eaten by herbivorous animals, and herbivorous animals are eaten by carnivorous animals. It might seem, therefore, that the number of carnivorous animals is limited by the available grass for grass-eating animals. But the balance of life is maintained by complex relations between many kinds of living things. When a grasshopper lays its eggs, the animals that can use the eggs as food begin to destroy them if they find them. If the eggs hatch, the young grasshoppers begin at once to eat the tender leaves of grass and other vegetation. When there is a large number of grasshoppers, there is danger of destruction of the kinds of vegetation that are used as food, and in any case the vegetation may be held in check. But birds feed upon grasshoppers, a single bird often eating in one day as many as the entire brood of one mother insect. In California a meadow lark was known to eat 314 grasshoppers in one feeding, and flickers have been known to devour over 5000 ants in one day. Obviously, the insects that survive are the ones which, while getting their own food, escaped the birds and also the diseases and climatic dangers that surrounded them.

The birds that devour the insects are themselves the food for other animals; they too are in danger of disease, cold, heat, and drought, and but few of their kind survive. Every natural region is to be looked upon as a society of living things, each one of which bears certain definite relations to some or many of the others. The squirrels in the woods thrive fairly well and in undisturbed nature their number remains fairly constant. If they increase too rapidly their food supply becomes too small or their enemies thus find a larger supply of food and likewise thrive, and in so doing reduce the number of squirrels. If the squirrels are removed from their normal regions, where they play a part in the balance of life, they may fail completely or may find new and unusual conditions well suited to them. How closely living things

are related to their surroundings may be shown by supposing a change in living places between a wolf of the Western plains, a squirrel of the Central States forest, and a fish of the Gulf of Mexico. None of these would survive if placed in the region in which the others live.

Man has disturbed the natural balance of life wherever he has gone. When he cuts a forest, plows a field, drains a swamp, or builds a city, many kinds of life are destroyed either directly or because the necessary conditions of life are removed. Agriculture and horticulture, in fact, are attempts of man to introduce new kinds of life where they did not exist. The destruction of the wheat crop by insects, of cotton by the boll weevil, and of apples by the codling moth are evidence that as yet man has not succeeded in maintaining his artificial balance of life without great loss.

393. Types of disturbance of nature's balance of life. The common rabbit was introduced into Australia and, finding favorable conditions, multiplied astonishingly. Under favorable circumstances a pair of rabbits will produce each year six litters averaging five young in each. Since rabbits feed upon vegetation, when present in large numbers they competed with cattle and sheep to such an extent that the grazing industry was almost destroyed in some sections of Australia.

Professor Sidney Dickinson says of rabbits:

> The original pair might be responsible in five years for a progeny of over twenty millions. That the original score that were brought to the country have propagated after some such ratio, no one can doubt who has seen the enormous hordes that now devastate the land in certain districts. In all but the remoter sections the rabbits are now fairly under control; one rabbiter with a pack of dogs supervises stations where one hundred were employed ten years ago. Millions have been killed by fencing in the water holes and dams during a dry season, whereby they died of thirst and lay in enormous piles against obstructions they had frantically and vainly striven to climb, and poisoned grain and fruit have killed myriads more.

Another great pest to the settlers is developing in the foxes, two of which were imported from Cumberland some years ago by a wealthy station owner, who thought that they might breed and give himself and friends an occasional day with the hounds. His modest desires were soon met in the development of a race of foxes far surpassing the English variety in strength and aggressiveness, which not only devour many sheep, but out of pure depravity worry and kill ten times as many as they can eat. When to these plagues is added the ruin of thousands of acres from the spread of the thistle, which a canny Scot brought from the Highlands to keep alive in his breast the memory of Wallace and Bruce, and in New Zealand the blocking up of rivers by the English water cress, which in its new home grows a dozen feet in length and has to be dredged out to keep navigation open, it may be understood the colonials look with jaundiced eye upon suggestions of any further interference with Australian nature.

Not to be outdone by foreign importations, the country itself has shown in the humble locust a nuisance quite as potent as rabbit, fox, or thistle. This bane of all men who pasture sheep on grass has not been much in evidence until within the last few years, when the great destruction of indigenous birds by the gun and by poisoned grain strewn for rabbits has facilitated its increase. The devastation caused by these insects last year was enormous, and befell a district a thousand miles long and two thousand miles wide. For days they passed in clouds that darkened the sky with the gloomy hue of an eclipse, while the ground was covered with crawling millions, devouring every green thing, and giving to the country the appearance of being carpeted with scales. It has been discovered, however, that before they attain their winged state they can easily be destroyed, and energetic measures will be taken against them throughout all the inhabited districts of Australia whenever they make another appearance.

CHAPTER XXXIII

PARENT AND OFFSPRING

394. Questions for Discussion. 1. Examine a dozen or more ears of corn of the same kind and note the ways in which they vary. Can you find two ears of corn exactly alike? **2.** Of all the human beings you have ever met, are any two exactly alike? **3.** In a herd of 100 or 1000 pigs, horses, or cattle are any two exactly alike? **4.** Are any two children of the same parents exactly alike? Are the children of the same parents more alike than they are like the children of other parents? **5.** What is meant by the law of variation? the law of resemblance? Do these laws disprove one another? **6.** What advantage was taken in Texas of the possibility of hybrid production in the case of the Hereford and Zebu cattle? **7.** How does artificial selection differ from natural selection? **8.** To what extent have domesticated cattle and horses served to determine by artificial selection what kinds of native plants may remain in our pasture lands? Do the growth habits of the plants which remain in pasture lands help to explain how they have succeeded in the struggle for existence? **9.** How has artificial selection in horticulture and floriculture affected such plants as apples, oranges, and chrysanthemums? **10.** Potatoes formerly developed seeds from the flowers at the tops of the plants. It is said that potato seeds are no longer developed in the United States. How can you account for this fact?

395. Individual differences. A casual observer, when looking at a forest, would say that many of the trees are alike. As soon as he looks closely and attempts to find two that are exactly alike he finds himself in difficulty. It is highly improbable that any forest, however large, contains two trees exactly alike. It will be instructive to try to find two exactly like objects of the same kind; for example, leaves of an oak or maple tree, pebbles on the shore of a lake or bank of a stream, or chickens or pigs in a barnyard.

While we should have difficulty in finding like objects of the same kind, we should rarely fail to recognize the relationship of the same kind of objects. We can recognize oak trees, and many people can distinguish between red oaks, white oaks, black oaks, etc. Even the descendants of a given set of parents bear such resemblances that we readily recognize their relationship. One family may have common characteristics that separate them from other families of children, but the different members of the family have distinctive characteristics.

Fig. 177. Variation in wheat

These heads are taken from wheat that was grown by the Pima Indians. Note the wide differences in characters of the heads. The number of inferior heads is so great that the yield would be small. Photograph by R. M. Mead

396. The nature of variation. Individuals of the same kind may differ from one another in almost every feature (fig. 177). If one selects the most widely different grains of corn that he can find on a single ear, he will usually be surprised at the variation. This is still better shown by selecting grains from different ears grown in different places. These are merely form and surface variations. Other kinds of variations in corn will be discussed later.

Equally great variations are found in other seeds. For instance, the seeds of the common ragweed usually have

distinct spines upon the surface, but the number of spines varies. The form and surface of one hundred seeds were studied. The table below shows the variation found in the number of spines in these seeds:

Number of spines	1,	2,	3,	4,	5,	6,	7,	8,	9
Number of times occurring	1,	3,	7,	9,	25,	37,	25,	12,	1

The plant known as "Spanish needles" has conspicuous yellow ray flowers. The number of the ray flowers varies, though this variation is often unnoticed. A count of three hundred and fifteen heads of this plant was made, and the following table resulted:

Number of ray flowers	3,	4,	5,	6,	7,	8,	9,	10,	11
Number of times occurring	2,	3,	8,	16,	52,	221,	9,	0,	1

It is not only the form or the number of parts that varies but the chemical composition also. In connection with attempts to grow the best types of corn for the different needs of agriculture and other industries, careful studies were made to determine the percentage of oil and of protein substances in corn. It was found that in some of the ears the percentage of protein was as high as 12.54 per cent, while in others it was as low as 8.96 per cent. The oil content also ranged from 5.39 per cent to 4.03 per cent.

397. Hybrids. One of the best breeds of cattle for the beef-producing sections of the United States is the Hereford (fig. 178). In some parts of the country Herefords and other breeds of cattle have been seriously affected by a disease carried by the cattle tick, and the cattle industry has suffered greatly from this cause. The zebu, or Brahman bull, of India (fig. 179) is immune to the tick and is thus free from the disease which the tick carries. The zebu is not ordinarily regarded as being as good for beef production as our native cattle. It occurred to certain cattle growers to produce cattle by interbreeding Herefords and zebus, in the hope that the

offspring might possess the desirable beef qualities of the Hereford with the tick immunity of the zebu. As a result of this experiment offspring were produced (fig. 180) showing various characteristics of the two kinds of parents. Offspring produced by crossbreeding are known as hybrids.

Some of the cattle produced as a result of the experiment just cited resemble the Hereford, some resemble the zebu,

FIG. 178. Hereford cows

One of the breeds of domesticated cattle. Photograph by Robert K. Nabours

and some bear partial resemblance to both parents. Some of the offspring retain the bodily form of the Hereford and the zebu's immunity to the cattle tick. Those individuals which retain these qualities are now being used as parents for the production of other cattle, with the hope that this new breed will retain the desired qualities. If this can be accomplished it will give us the solution of an important practical problem.

Among plants and animals many hybrids are constantly being produced. Hybridization presents an important method of production of variations.

398. Natural and artificial selection. Whenever variations occur we may in a measure determine which variants shall have a chance to reproduce their kind. In the next generation variations will again appear, and selection will again be necessary if we desire to perpetuate the type we began with. It is possible to make a race of plants or animals less variable

FIG. 179. A bull of the Brahman, or zebu, breed from India

The hump over the shoulders and the backward pointed horns are characteristic features of this animal. Photograph by Robert K. Nabours

by selecting constantly for a certain type and by eliminating the variations which do not conform to that type.

Man decides which of all the variations he desires for his own use and then tries to maintain these particular types and eliminate the others. This constitutes artificial selection. In open nature, through natural selection, those things that can live are the ones that do live. The animals of the extremely cold countries vary in the thickness and heat-retaining qualities of their coats of fur. They vary also in their fleetness in pursuit of food, in their ability to escape enemies,

and in their physical endurance of the rigor of their environment. Those whose variations best fit them for their environment are usually the ones that live. The others die of hunger or of physical hardships or by being caught and killed by their enemies. In succeeding generations, year after year, variations occur, and the animals that can endure the conditions of their environment are the ones that live.

FIG. 180. Hybrids from a zebu and Hereford cattle

The humps and horns in some cases show relationship to the zebu, but the coloring and general conformation of body are usually like those of the Hereford. Some of the hybrids, like the zebu, are free from the tick, which carries the germs that cause Texas fever. Photograph by Robert K. Nabours

399. Changes in environment. Any change in the environment affects the living things within it. The changes in plant and animal life are in themselves fundamental changes in the environment, for plants and animals constitute a most important part of the environment. For example, when wolves, foxes, and rabbits occur in undisturbed nature in their usual numbers, only those rabbits can live which can escape from the wolves and foxes and other enemies. If we suppose that there is an epidemic of disease which kills off all the wolves and foxes over a territory of one hundred

square miles, the environment for rabbits is greatly altered. Under such conditions many rabbits can live which could not live if the wolves and foxes were present in their usual numbers. Thus the changed environment, so far as these factors are concerned, is favorable to the life of a larger number of rabbits.

But what do rabbits live upon? In one region in which they live in winter they eat large quantities of buds from low shrubs (as young trees of sassafras, hawthorn, etc.). An unusual increase of rabbits thus greatly affects the environment for plants upon which rabbits feed. The supply of food may become exhausted, and starvation of the rabbits may result largely because so many of them have succeeded in escaping animals that prey upon them.

The environment changes, therefore, for wolves and foxes, for rabbits, and for the plants upon which rabbits feed, but these are only a small part of the factors that make up the natural environment in any region. This constant change in the environment means constant change in the kinds of things that may live. Variants that can live in one environment may sometimes be unable to live in the same region when it has undergone extensive changes.

400. Results of natural selection. We have seen from our studies of overproduction and variation that many variable forms are introduced upon the earth, most of them failing to live to adult size and perpetuate their kind. The living plants and animals now found are to be looked upon as the few that have persisted. Not only this, but natural selection is still going on, and we must not look upon the things now living as the final types of inhabitants of the earth. They are merely the results of nature's processes at this time, and nature is still working.

401. Artificial selection. Man selects those variations that give promise of being advantageous to him in some way. He tries to adjust the environment about these plants and

animals so as to produce the best results. If he wishes to produce an animal that will furnish beef in large quantities, he selects and grows the variety which most nearly resembles his ideal. He then tries to create the most favorable environment by careful feeding, pasturing, and housing, and by

FIG. 181. Diversity of form produced by selection and breeding

Five varieties of chrysanthemum. All chrysanthemums have descended from a common ancestor similar to the small upper left-hand specimen

warding off disease. In the same way sheep, swine, driving-horses, corn, wheat, coffee, carnations, and roses are selected and grown under artificial conditions, and results are produced which are often very unlike those found in undisturbed nature (fig. 181).

402. Progressive results of artificial selection. The Illinois Agricultural Experiment Station has performed some important experiments to determine the possibilities of changing the food values in different kinds of corn. The accompanying

tables, based upon ten years of experimentation with corn-breeding, show that by constantly eliminating the undesired variations and maintaining the desired ones it is possible to accentuate certain characters. In studying the first of these tables note the gradual increase of the percentage of protein materials in one lot and the corresponding decrease in the other lot. For feeding purposes the corn with the largest amount of protein would be more valuable.

TEN GENERATIONS OF CORN WHICH WAS BRED FOR INCREASE AND DECREASE OF PROTEIN

YEAR	HIGH-PROTEIN PLOT; AVERAGE PER CENT PROTEIN		LOW-PROTEIN PLOT; AVERAGE PER CENT PROTEIN		PER CENT OF DIFFERENCE BETWEEN CROPS
	In seed planted	In crop harvested	In seed planted	In crop harvested	
1896	—	10.92	—	10.92	.00
1897	12.54	11.10	8.96	10.55	.55
1898	12.49	11.05	9.06	10.55	.50
1899	13.06	11.46	8.45	9.86	1.60
1900	13.74	12.32	8.08	9.34	2.98
1901	14.78	14.12	7.58	10.04	4.08
1902	15.39	12.34	8.15	8.22	4.12
1903	14.30	13.04	6.93	8.62	4.42
1904	15.39	15.03	7.00	9.27	5.76
1905	16.77	14.72	7.09	8.57	6.15
1906	16.30	14.26	7.21	8.64	5.62

For the manufacture of corn oil it is desirable to secure varieties of corn having a large proportion of oil. In the table on page 392 it will be possible to note the gradual separation of two races of corn which differ greatly in the proportion of oil present, though all have descended from the same original lot of corn. The figures at the top and in the margins represent percentages of oil; those in the body of the table indicate the number of ears of the indicated composition.

PROGRESSION IN HIGH AND LOW OIL CONTENT OF "ILLINOIS" CORN

YEAR	AVERAGE % OIL IN SEED	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	8.50	AVERAGE % OIL IN CROP
1896											1	15	20	41	36	25	15	5	4	1											4.70
1897	High 5.39									1			10	15	19	24	3	7	1												4.73
	Low 4.03									5	7	9	7	7	5																4.06
1898	High 5.20											1	7	29	37	50	35	24	22	6	2	2	1								5.15
	Low 3.65								8	9	31	31	19	9	1																3.99
1899	High 6.15												1		2	10	16	22	24	18	12	3									5.64
	Low 3.47						1	2	5	32	36	36	23	8	1																3.82
1900	High 6.30														1	1	3	9	18	16	30	18	9	2	1						6.12
	Low 3.33					1	3	8	32	39	32	20	6	3																	3.57
1901	High 6.77															2	3	10	13	26	21	28	15	7	1						6.09
	Low 2.93						2	12	34	43	29	5	1																		3.43
1902	High 6.95															2	5	3	10	13	18	16	13	9	1						6.41
	Low 3.00				1	6	34	19	16	9	5																				3.02
1903	High 6.73																	1	10	10	19	18	21	13	5	2	1				6.50
	Low 2.62				1	3	26	33	22	5																					2.97
1904	High 7.16														1					3	9	8	12	15	18	18	8	6	2	1	6.97
	Low 2.80				3	7	42	31	15	4																					2.89
1905	High 7.89																				4	9	19	15	21	17	19	7	5	4	7.29
	Low 2.67		1	4	21	42	31	19	1																						2.58
1906	High 7.86																			1		5	9	24	16	32	20	8	2	3	7.37
	Low 2.20	1		4	15	34	36	19	10	1																					2.66

It is likely that if all these samples of ears of corn had been left to grow side by side, no such differentiation of the two races would have developed. They have been separated from one another only by selection and perpetuation of the desired types and by elimination of the others.

403. Artificially selected types not easily maintained. The plants and animals developed artificially by man could not persist long in their present form if they were removed from his care. A corn field, if left from year to year, would probably, even in its second year, be more conspicuous for its weeds than for its corn. Farm animals, if left to shift for themselves, would doubtless, in most cases, soon cease to exist or would rapidly change their habits and appearance. A poultry yard, if deserted by man, would soon be cleared of chickens by marauding animals, by disease, or by starvation. A rose garden requires constant care to prevent its losing the high type of flower production desired by man. An apple orchard under relaxation of care very soon becomes infested by disease and reverts to relative nonproductivity. Man's artificially selected types are in a condition of high tension, which is soon relaxed, partly or wholly, when he ceases to select and to care for them. These conditions are well shown in neglected orchards and on abandoned farms, where cultivated plants are gradually giving way to native wild plants.

404. Inheritance. Much that has been said bears more or less directly upon the topic of inheritance. "Heredity is the rule of persistence among organisms." It is an old saying that "like begets like," and while we know that organisms vary from one generation to another, we also know that they resemble one another with varying degrees of resemblance. We expect individual characteristics of parents to be more or less represented in the individual characteristics of offsprings. Francis Galton studied in a large number of families the relations between the average height of the parents and

the average height of the adult children. Some of these relations appear in the following table:

Average height of parents	Average height of children
72.5	71.4
71.5	69.9
70.5	69.5
69.5	68.6
68.5	68.0
67.5	67.6
66.5	67.1
65.5	66.8
64.5	65.6

In no case is the average height of the children widely different from that of the parents. It is evident that children of tall parents are likely to be tall, though not averaging as tall as their parents, and that children of short parents are likely to be short, though not averaging as short as their parents. It must be understood that there may be exceptionally tall or exceptionally short children in any family and that such cases are included in the averages given.

405. Heredity and the future of the race. Few things contribute more to successful living than a sound and vigorous body, and such is a heritage of untold value. An unsound body is also a heritage, but a burdensome one. We cannot emphasize too strongly the importance of making sure that no avoidable tendency to disease and no abnormally weakened bodies are passed on to succeeding generations. There are few tragedies more awful than that of being born into the world weighted down with a weakened body. Such bodies are given to innocent people because parents or society did not know enough or care enough to prevent the inheritance of things that make successful life hard, often well-nigh impossible, for the offspring. It is high time for the human race to recognize and use what is known of biological inheritance. We produce high types of corn and cattle because

we want to make money from the product. What are we doing to make sure that the next generation of men and women shall be physically, intellectually, and morally as effective as the laws of heredity will enable us to make them?

406. Controlling human environment. No one of us can now determine what our own heredity shall be. That has been settled for us. We can decide, in a measure, what shall be the heredity of those who are to come after us. We can do much toward changing our environment so that defects in our own heredity may not lead to consequences so undesirable as might otherwise result.

A weakened body may often be strengthened by judicious care and exercise so that a hereditary weakness may be almost or entirely overcome. We can curb a hereditary tendency until it is almost or quite inoperative. We can create for ourselves new and artificial environments which shall enable us to turn a harmful or worthless hereditary tendency into efficiency and a high type of usefulness. It is a heavy task to stem the tide of nature, and he who would do it must prepare for an effort in which some have failed and some have succeeded. It is worth the effort, for what is better than to turn weakness into efficiency?

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